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Nitrogen based establishment and seedbanking potential of Kentucky bluegrass and perennial ryegrass in athletic fields

by

Andrew Hansen Hoiberg

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Horticulture

Program of Study Committee:
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2012

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TABLE OF CONTENTS

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GENERAL INTRODUCTION

An estimated 48 million youth, ages 5 to 17, participate in sports programs throughout the United States (Seefeldt and Ewing, 1996). The world governing body of soccer, FIFA, represents approximately 200 million active players worldwide (Dvorak and Junge, 2000). There are approximately 5 million participants in organized youth baseball leagues in the United States (Marshall et al., 2003), and in 2010, over 250,000 youths participated in Pop-Warner sanctioned football programs, while US Youth Soccer currently has 3 million members between the ages of 5 and 19. There is no reason to believe that these numbers will see a significant reversal in the foreseeable future. Further, most participation statistics available represent youth sports, as numbers representing adult recreational activities are of less interest to the general public; however, athletes of all ages contribute to cumulative effects of traffic that are manifested on natural grass athletic fields around the world. Overuse of fields has been and continues to be a common problem throughout the United States, resulting in major damage to turfgrass due to excessive vehicular and foot traffic (Carrow and Petrovich, 1992).

Traffic based research has become commonplace in turfgrass research programs over the past 35 years (Shearman and Beard, 1975; Bourgoin and Mansat, 1981, Cockerham et al., 1990; Minner et al., 1993; Bonos et al., 2001; Carrow et al., 2001, Minner and Valverde, 2005; Hoiberg et al., 2009; Trappe et al., 2011; Thoms et al., 2011). Traffic research has broad range; from anatomical and physiological traits in species related to wear tolerance (Beard et al., 1974), to root zone construction (Canaway, 1983), to breeding for wear tolerance (Bonos et al., 2001), to development of artificial wear machines (Carrow et al., 2001), to development of strategies to combat excessive wear (Minner and Valverde, 2005; Hoiberg et al., 2009). Continually increasing demand on natural grass fields and potential for second generation artificial turf to replace them puts pressure on turfgrass researchers to further develop and refine strategies to ensure sustainable natural grass fields. It is important to keep in mind that key objectives in athletic field research are to provide a playing surface that wears well while being managed within an acceptable budget, and most importantly provide a surface that players can enjoy while minimizing risk of injury (Baker and Canaway, 1993).

The use of first generation artificial turf fields ended in the NFL in 2010 when the St. Louis Rams replaced the AstroTurf playing surface at Edward Jones Stadium with a second generation infill system. Some 13 years earlier, the newest generation of synthetic turf was inaugurated in the USA at Ringgold High School in Monongahela, PA, employing a combination of sand and crumb rubber to infill a horizontal backing that supports numerous nylon, polypropylene, or polyethylene fibers (McNitt, 2005). Two main differences between newer systems and those of generations past are the length, or pile, of the fibers to mimic natural grass, and the infill of sand, a combination of sand and crumb rubber, or crumb rubber alone. Different companies have patented different proprietary infill mixtures to make their product unique and marketable. Although artificial fields have their place in the grand scheme of athletic fields, there are still unanswered questions about them and many players still prefer a natural grass surface to an artificial one.

In the 2010 NFLPA (National Football League Players Association) field surface survey, on average, 82% of players believe that artificial infilled fields are more likely to contribute to injury, 89% of players believe artificial infilled fields cause more soreness and fatigue when played on, almost 90% of players think artificial infilled fields are more likely to shorten their career, and almost 70% prefer to play on natural grass fields. Further, artificial infill turf systems react very quickly to solar radiation, and during summer months can easily exceed temperatures of > 50°C, jeopardizing the safety of those using the field (DeVitt et al., 2007). Disposal of these systems after a usable lifespan is another potentially negative aspect; however, many early installations are still in place and this has not yet become a widespread issue. Due to reasons outlined above, as well as high initial cost to install artificial turf systems, furthering knowledge of natural grass systems and how to make them more sustainable is of utmost interest.

Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) are the predominant species used on cool season athletic fields in the United States, as both species exhibit exceptional wear tolerance (Sorochan, et al., 2001). Moreover, use of perennial ryegrass and Kentucky bluegrass as over-seeding species is quite common (Minner et al., 2008). Perennial ryegrass is desirable for athletic fields due to rapid germination and establishment (Larsen and Bibby, 2004) and relative wear tolerance (Beard, 1973); however, it is a bunch type grass, lacking rhizomes or stolons that contribute to recuperative ability. Kentucky bluegrass is desirable for athletic fields because of good wear tolerance and recuperative potential due to its aggressive growth habit via rhizomes after it reaches tillering stage; however, it is slow to establish compared to perennial ryegrass (Beard, 1973; Brede and Duich, 1982). Minner and Valverde (2005) found Kentucky bluegrass and perennial ryegrass to have equal wear tolerance when subjected to simulated traffic. Breeding efforts continue to improve wear tolerance on both species and traits such as prostrate and/or pseudo-rhizomatous growth are being selected for in perennial ryegrass to expand its applicability in the athletic field market. There are myraid cultivars of each species, and fortunately traffic tolerance data from the National Turfgrass Evaluation Program (NTEP) exists to assist turf managers and academic researchers in selecting cultivars that are best suited for heavily trafficked areas and research applications.

Strategies to Sustain Turf Cover and Speed Establishment

Seeding Rates & Schedules

Soil compaction and wear injury are the stresses associated with traffic on athletic fields. Wear injury results from direct pressure, scuffing, or tearing on turfgrass plants (Carrow and Petrovich, 1992), affecting aboveground tissue, while soil compaction caused by traffic results in increased bulk density, a general loss of soil structure, and a reduction in aeration status and water infiltration (Beard et al., 1974), all of which have negative impacts on overall root and plant health.

Although thatch and mat buildup are generally undesirable in turfgrass, a small amount can reduce surface hardness, buffer soil temperature extremes, and improve resilience and wear tolerance of the field surface (Beard, 1973). Further, maintaining aboveground biomass to prevent exposed soil is important for athletic field managers as soil compaction is accelerated when the field wears away and bare soil is exposed (Minner and Valverde, 2005). Due to earthworm activity, it is rare to find athletic fields in Iowa with excessive thatch/mat buildup, and often, recommendations are made to increase aboveground biomass via over-seeding to prevent aforementioned conditions from occurring.

When examined outside the context of heavily trafficked athletic fields, higher than normal seeding rates result in a dense population of weak, spindly plants competing for essential water, sunlight, and nutrients. Studies allowing long term establishment of turfgrass seeded at higher than normal rates generally conclude that excessive seeding rates should not be used due to these reasons (Madison, 1966; Parr, 1981; Rossi, 1997). However, when seeded immediately prior to, or in the presence of traffic, the high density of turfgrass plants resulting from higher than normal seeding rates can be mechanically thinned by traffic such that competition among plants will not result in decreased turf cover (Minner et al., 2008). High seed counts overcome injury to seeds, emerging seedlings, and subsequent seedling growth caused by excessive traffic. Minner and Valverde (2005) indicate the need to understand traffic tolerance of turfgrass seedlings to develop recommendations for a systems approach to reducing athletic field overuse.

Canaway (1983) concluded that aboveground biomass appears to be the most important single variable in relation to shear strength and ball bounce resilience on athletic fields prior to wear. Strategies to increase aboveground biomass have been examined in the past by increasing seeding rates (Minner and Valverde, 2005; Crossley, 2006; Minner et al., 2008; Hoiberg et al., 2009) over what have historically been considered optimal. Higher than normal seeding rates applied to mature stands of perennial ryegrass and tall fescue (*Festuca arundinacea* Schreb.) resulted in increased turf cover when seeded concomitantly with traffic treatments (Minner and Valverde, 2005). Perennial ryegrass cover increased with seeding rate up to 150 g m^{-2} when traffic and seed treatments were applied simultaneously during a simulated fall US football season (Minner et al., 2008). An increase of two to three times the normal seeding rate was recommended when traffic was applied after a three month establishment period of perennial ryegrass (Crossley, 2006), and seeding rates up to 18 times the normal rate resulted in the greatest annual ryegrass (*Lolium multiflorum* L.) turf cover during traffic (Hoiberg et al., 2009). By broadcasting seed over high traffic areas, athletic field managers can take advantage of player's cleated shoes to "cleat-in" the seed, creating seed to soil contact necessary for germination. This can increase turf cover during the beginning and middle parts of the autumn traffic season when temperatures are still suitable for germination of cool season grasses.

When examining seeding strategies to maximize turf cover, an important consideration is how to budget a given amount of seed. Generally, two autumn seeding schedules are used:

sowing the seed all at once in early September or dividing the same amount of seed into repeated, lower rate applications throughout the traffic season. The first schedule has potential downfall in using budgeted seed at once, leaving none to over-seed fields later in the season. Seeding in multiple, even applications, has potential downfall in that late autumn seeding events, after 1 Oct., can result in poor establishment due to an increased risk of seedling injury from low temperatures (Laude, 1956; Turgeon, 2005). Seedlings germinating after 1 Oct. merely provide green cover as there is not ample time to mature and contribute to a wear tolerant stand.

When compared to dividing the same amount of seed into multiple applications, a single seeding of perennial ryegrass in early September produced twice as much turf cover through an autumn traffic season and into the following spring recovery period (Minner et al., 2008). Similarly, Hoiberg et al. (2009) found that a single seeding of annual ryegrass was more beneficial for maximizing turf cover during a traffic period when compared to dividing the same amount of seed into multiple applications. Planting seed during ideal germination conditions will maximize turf cover when over-seeding worn areas of athletic fields and can result in reduced labor costs for athletic field managers (Hoiberg et al., 2009). No studies that the author is aware of have concluded that dividing seed into multiple applications is more beneficial in maximizing turf cover than sowing seed at a single, higher than normal rate immediately before or simultaneous with traffic treatments.

Seedbanking

Seedbanking is a term often heard as a recommendation for athletic field managers to help sustain turf cover in the presence of traffic. The term is associated with heavy over-seeding, and whether a seedbank is actually being created remains unanswered (Sherratt et al., 2009). Building a seedbank in the context of applied turfgrass management has received attention in popular press (Stier, 2008; Sherratt et al., 2009); however, it is limited to forage, prairie, and grassland management in refereed literature (Rampton and Ching, 1966; Thompson, 1987; Cardina et al., 1996; Chauhan et al., 2006; Garrison and Stier, 2010). Moreover, anecdotal reporting of seed germinating well after the prescribed window is common in the turf industry, but again, applied research to prove seedbank formation with annual and perennial turfgrasses is scarce.

Seedbanks are studied extensively in weed science, as weeds form varying degrees of seedbanks that are necessary for species survival (Roberts, 1981; Gross and Renner, 1989; Cardina et al., 1991; Yenish et al., 1992; Cavers, 1995; Dessaint et al., 1997; Zhang et al., 1998). Seedbanks in grasses are not entirely alien, however. Annual bluegrass (*Poa annua* L.), although a weedy species, is known for forming a dense and persistent seedbank which is responsible for its ability to reinfest areas where it has been controlled or perished (Shem-Tov and Fennimore, 2003).

Two types of seedbanks exist in nature: transient, in which seeds persist in soil for no more than one year, and persistent, in which seeds persist for many years. Environmental factors such as light, temperature, moisture, and various chemicals can impact seasonable germinibility, giving species of plants characteristic emergence patterns (Bewley and Black, 1994). Seed input and subsequent seedbank development differs between overseeding by atletic field managers and natural input. In natural seedbanks, plants deposit seed through fecundity, i.e. the plants themselves are responsible for forming seedbanks to ensure survival. When athletic field managers attempt to build a seedbank, it is through the process of human input, i.e. the turf manager is responsible for increasing the population of germinable seeds in the soil profile. Weeds and other seedbank forming plants have evolved to develop dormancy mechanisms that will ensure relative long term survival by banking seeds and staggering germination to grow when environmental conditions warrant. Turfgrasses, on the other hand, are selectively bred for desirable characteristics such as color, wear tolerance, density, etc. and then cultivated under controlled conditions by farmers. After harvest, turfgrass seed must undergo a process of afterrpiening before being sold to break seasonal dormancy, ensuring that seeds are ready to germinate when purchased (Funk, 2002). The difference between the two mechanisms is obvious and would lead one to believe that turfgrasses have a disadvantage in evolutionary dormancy, and thus, seedbank development traits. Generally stated, grasses used extensively for cultivation (e.g. turfgrasses) have little or no seed dormancy, but in wild grasses, deeper dormancy mechanisms are not uncommon, as this ensures survival (Langer, 1979).

Seed size and shape have been related to seedbank potential; large seeds are less likely to infiltrate soil and access small openings therein (Bekker et al., 1998). Similarly, relatively larger seeds from *Festuca* spp. and *Lolium perenne* are less prone to earthworm ingestion when compared to smaller seeds from *Poa* spp. and *Agrostis* spp., and are therefore less likely to form seedbanks than smaller seeded species (Thompson, 1987) as ingestion from earthworms is important for both burial of seeds and subsequent return to the soil surface via casting. Thompson (1987) concludes that it is advantageous for seeds of species forming persistent seedbanks to be ingested by earthworms, and characteristics such as small size, compact shape, and lack of awns or hairs will predispose them to ingestion.

Seeds of Kentucky bluegrass and perennial ryegrass have shown limited persistence in soil. Rampton and Ching (1966) showed that perennial ryegrass had very limited capacity for longevity and dormancy maintenance and suffered the most rapid deterioration of any seeds in the experiment, while Kentucky bluegrass showed promise in year one only to demonstrate a sharp decline in viability in year two. Seeds from both annual and perennial grasses can compose a large portion of seed numbers present in grasslands; however, due to synchronous germination in autumn, seeds from *Lolium multiflorum* and *Lolium perenne* make little or no contribution to the seedbank (Roberts, 1981). Given these findings, is continual over-seeding of turfgrasses really forming a seedbank, or are turf managers simply providing a constant source of fresh seed to germinate in bare areas (Stier, 2008)?

One potential limitation for turfgrass seedbank formation is the position of seeds as they are applied and worked into the soil profile. Seeds are distributed in different strata of soil by processes of broadcasting, cleating-in, and cultivation; depth of distribution is related to depth of cleat or cultivation penetration. Only seeds that can obtain requisite moisture, soil contact, nutrients, and sunlight are in prime position to germinate and those that are not may eventually be brought into the necessary position by continual thinning of existing grass and turnover of the soil.

Depth of cultivation practices may differ depending on the time of year, reason for cultivation, and timing of cultivation relative to seeding. Similarly, the length of cleats worn by athletes range from 1.3 to 1.9 cm, and if cleating-in is the only method utilized by turf managers to incorporate seed into soil, it can be assumed that the majority of seeds will travel no deeper than 2.5 cm in the soil. One question that arises is how close to the surface must a seed be to ensure that it will germinate and benefit turf managers? Similarly, how can seeds that are too deep to germinate be brought into germinable position? Will whatever process is used to do so act as a destructive force to the existing sward? Lastly, is it worth being concerned with ungerminable seeds when more seed may be applied for low cost? Hoiberg et al. (2009) concludes that additional research is needed to explore the ability of turfgrass seed to develop a beneficial seedbank over a given time period. It appears as though we may force cool season turfgrass species to form transient seedbanks, although the degree to which they will benefit turf managers is questionable.

Nitrogen Based Establishment

Our interest in nitrogen rate as a method for speeding establishment of perennial ryegrass and Kentucky bluegrass stems from an antecedent study performed in fall 2008 that examined how increasing nitrogen rate on Kentucky bluegrass seeded at a normal rate would affect fall establishment. Results from that study indicated that increases in nitrogen rate from 100 to 500 kg total N ha^{-2} applied over 10 weeks increased turf cover (Hoiberg and Minner, unpublished data). What we were not able to assess was what impact increased nitrogen fertility had on traffic tolerance. Although increased nitrogen has been shown to decrease wear tolerance, it may be possible to increase nitrogen during establishment to increase biomass, then subject the sward to a hardening off period prior to traffic, possibly reducing negative effects of excessive nitrogen on wear tolerance.

Nitrogen is the most abundantly required and applied nutrient in turfgrass management and is high on the list of important cultural practices in establishment and maintenance of quality turfgrass (Turner and Hummel, 1992). Nitrogen is paramount to many different biochemical compounds and processes in plants, including: chlorophyll, and thus, photosynthesis; numerous amino acids, amides, and proteins, all of which constitute portions of the protoplasm; nucleic acids and hormones; and enzymes and vitamins, responsible for metabolic reactions within plants (Beard, 1973; Hull and Liu, 2005).

Nitrogen is very mobile and can take on many different forms in plants, soils, and the atmosphere (Christians, 2007). Plant available nitrogen exists in two forms, nitrate (NO_3^-) and ammonium (NH_4^+) with nitrate the predominant source in well drained soils of moderate pH (Marschner, 1995), as ammonium can be immobilized on cation exchange sites (Hull and Liu, 2005).

Nitrogen influences growth of turfgrass tissues, increasing rate of shoot and root growth as nitrogen rate increases; however, this response will reach a point where carbohydrate availability for protein synthesis becomes limiting, causing suppression of root growth and carbohydrate reserve, while shoot growth continues (Beard, 1973). Canaway (1984) found a rapid initial increase in aboveground biomass, followed by a leveling off and eventual decline at very high levels of nitrogen, which may be caused by increased moisture content of tissues and deceases in total cell wall constituents. Nitrogen fertilization has been shown to improve wear tolerance up to a threshold (Leyer and Skirde, 1980), at which the aforementioned factors can result in decreased wear tolerance (Beard, 1973; Canaway, 1984). Canaway (1984) found the optimum level of nitrogen to maximize perennial ryegrass wear tolerance was 200 – 300 kg N ha^{-1} yr^{-1}. Therefore, nitrogen fertility programs are designed to maintain a level of nitrogen such that shoot growth will not supersede root growth and development.

Nitrogen sources exist in many forms that differ in release mechanism; quick or slow, which is important in determining which fits a particular nitrogen fertility program. Quickly available nitrogen sources include inorganic salts, urea, and ureaformaldehyde products, while slowly available include natural organics, synthetic organics, and coated materials (Turner and Hummel, 1992). The cheapest nitrogen source for turfgrass professionals is urea (46-0-0), which is commonly used on turfgrass. Urea is produced by combining atmospheric nitrogen with methane to produce ammonia and carbon dioxide, which are then reacted under high pressure to form urea. Urea is highly soluble in water and is characterized by a quick release of short duration, leaching tendency, and foliar burn potential (Beard, 1973). For these reasons, urea based nitrogen programs should include multiple, light applications to minimize losses (Turner and Hummel, 1992). Further, urea should be followed closely by irrigation or rain to minimize volitalization (Watson, 1984).

Historically, nitrogen fertility programs included heavy spring fertilization, little or no nitrogen applied in the summer, and moderate applications in fall (Christians, 2007). This method can cause exhaustion of carbohydrate reserve before summer stress, resulting in deterioration in late summer before nitrogen applications resume in fall. Currently, fertility programs include lighter applications in spring to minimize exhaustion of carbohydrates, as-needed applications in summer, and a return to higher levels of nitrogen in fall (Christians, 2007). Despite current trends, development of site specific nitrogen programs are needed to provide the best possible sward for different scenarios. Turner and Hummel (1992) conclude that due to unreliable soil testing for nitrogen, recommendations remain largely empirical. Further, continued advances in cultivars and intensifying use of species have altered traditional management practices (Sorochan et al., 2005).

Nitrogen application timing is difficult to prescribe due to influences of sward composition, nitrogen source, soil texture and organic matter content, event schedules, climate, irrigation, microbial populations, and difficulty in identifying the status of different pools of nitrogen in the turfgrass system. Therefore, what works at one site may not be applicable to another, particularly when usage patterns differ. Multiple, light applications of fertilizer are crucial for seedlings to ensure that nitrogen is adequate for growth and development, but not at rates that will cause leaf burn or restricted growth of roots and lateral shoots (Turgeon, 2005). After seed is planted, fertilizer applications are generally not made until deemed necessary or at first mowing, however, we feel that applications starting when seedlings emerge can speed establishment, particularly with slow maturing species like Kentucky bluegrass.

The use of increased nitrogen to speed establishment is not new. Hummel (1980) reported more rapid establishment of Kentucky bluegrass and darker color with 97 kg N ha^{-1} when compared to 48 kg N ha^{-1}. Similarly, Madison (1962) concluded that nitrogen fertilizer increased population density without greatly affecting individual plant size. Still, optimum nitrogen rates during establishment of Kentucky bluegrass and perennial ryegrass on athletic fields to maximize turf cover have not yet been determined. Application timing and schedule relative to traffic will be an important consideration as applications made too near traffic may result in highly succulent turfgrass susceptible to attrition. On the other hand, nitrogen applied in advance of traffic could be used for rapid establishment and maturation. If combined with a period of hardening off to allow plants to reduce moisture content, mature stands of turfgrass could be ready for cleated wear before fields following a more traditional, year round nitrogen fertility program. Different rates of urea, evenly divided into weekly doses will be examined for their effectiveness in promoting quick establishment and maturation of both perennial ryegrass and Kentucky bluegrass.

Traffic Simulation

Traffic simulation that mimics real world cleated wear is an important component of research programs designed to evaluate wear tolerance in turfgrass species. Further, wear tolerance evaluations should be based on research conducted under specific conditions in which the target species will be used (Bonos et al., 2001). Multiple traffic simulation devices and techniques have been developed to duplicate real world traffic (Younger, 1961; Shildrick, 1971; Sherman et al., 1974; Canaway, 1976; Bourgoin and Mansat, 1981; Cockerham and Brinkmann, 1989; Carrow et al., 2001; Shearman et al., 2001). The desired outcome of simulated traffic stress is the same twofold effect of real world traffic stress, soil compaction plus wear. Early devices utilized a cleated roller that was simply rolled back and forth across plots to wear down turf (Shildrick, 1971). Using a differential slip drive to cause more realistic tearing of the turfgrass canopy and soil surface was first attempted by Canaway (1976) when he converted a rotary tiller into a traffic simulation device by using studded rollers mounted on two axels. Cockerham and Brinkmann (1989) developed the user friendly Brinkmann Traffic Simulator to be towed behind a tractor, easily covering a large number of plots, while causing soil compaction and turfgrass wear.

Pertaining to our research program is the machine developed by Carrow et al. (2001) at the University of Georgia (GA), that accomplishes both soil compaction (SC) and wear (W). The GA-SCW provides compaction from the weight of the machine and wear from the differential slip action of the middle cleated drum (Carrow et al., 2001). The GA-SCW is also self propelled and can be operated in both forward and reverse to speed application of simulated traffic over large areas.

Plot Rating & Digital Image Analysis

The most widely used and accepted procedure for obtaining quality data on turfgrass is the visual quality system which is based on color, density, uniformity, or overall appeal of a sward to researchers evaluating plots (Skogley and Sawyer, 1993). This system is often scored with values ranging from one to nine, where one equates to dead or dormant turf, and nine represents the finest, dark green turfgrass.

When rating plots subject to traffic, repeated visual assessment of percentage cover of the desired species is often employed to determine differences in traffic tolerance among treatments.

Shearman and Beard (1975) found relative agreement among the following methods for differentiating wear tolerance: visual ratings, percent total cell wall, percent verdure, and chlorophyll content. Specifically, after traffic treatments, visual ratings were correlated to percent total cell wall remaining, percent verdure remaining, and percent chlorophyll content/unit area.

However, visually assessed color ratings, although providing rapid data acquisition and requiring less equipment expense, are subjective measures that are susceptible to human bias and are less precise than quantitative measures (Horst et al., 1984; Karcher and Richardson, 2003). When evaluated at a Northeast Regional Turfgrass meeting in 1975, it was concluded that experienced researcher's assessments of quality, density, and resistance to leaf spot were correlated, while their evaluations of turf color were not (Skogley and Sawyer, 1993). Karcher and Richardson (2003) conclude that timely quantification of turfgrass color with user friendly equipment would increase validity of results without altering the rapidity and convenience of visual assessments.

Over the past few decades, digital photography and digital image analysis have been employed to document and share images, detect color differences, canopy coverage, and senescence in agricultural crops, and to quantify turf coverage with increased precision (Richardson et al., 2001; Karcher and Richardson, 2003). Purcell (2000) showed that canopy coverage and subsequent light interception could be determined using digital images combined with a commercially available software program, SigmaScan (SPSS, Inc., Chicago, IL). With this development, Richardson et al. (2001) hypothesized that digital image analysis could be utilized to collect turfgrass coverage data in a timely fashion that eliminated the subjectivity of traditional visual estimates. One major benefit to digital image analysis is the ability to collect data during the growing season and archive images for analysis during months when field work is not being performed.

Changing light conditions were a potential limitation of repeated color measures with digital image analysis. However, standardized light boxes have been developed (NextGen Research, Willamette Valley, OR) to keep the camera the same distance from the ground for each image as well as providing consistent artificial lighting that mimics optimal daylight conditions. Regardless, it has been proven that digital image analysis can accurately and consistently measure both turfgrass cover and color with assistance from SigmaScan (Richardson et al., 2001; Karcher and Richardson, 2003).

Since the integration of digital image analysis for turfgrass in the early 2000s, it has become commonplace in turfgrass research programs. A search on the Turfgrass Information File at Michigan State University retrieves 24 refereed manuscripts that used digital image analysis, all since the seminal work of Douglas Karcher and Michael Richardson at the University of Arkansas in 2001.

DISSERTATION ORGANIZATION

This dissertation is divided into five chapters. The first chapter examines background information regarding research done in the past and how the need for research contained herein was established. The second chapter is a manuscript that will be submitted to *The International Turfgrass Society Research Journal* describing the field and laboratory experiment with seedbanking potential of Kentucky bluegrass and perennial ryegrass in an athletic field setting. The third chapter is a manuscript that will be submitted to *The International Turfgrass Society Research Journal* describing a field and laboratory experiment dealing with Kentucky bluegrass and perennial ryegrass seed viability when planted to a depth similar to that when seeds are cleated into the ground by athletes. The fourth chapter is a working manuscript that will be submitted to *Crop Science* upon completion for an experiment that examines whether increasing nitrogen rate can speed establishment and maturation of Kentucky bluegrass and perennial ryegrass, thus preparing a sward for simulated traffic; traffic tolerance as a result of increased nitrogen will also be explored. The fifth and final chapter is a summary of results and general conclusions from the aforementioned experiments.

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SEEDBANKING POTENTIAL OF KENTUCKY BLUEGRASS AND PERENNIAL RYEGRASS IN ATHLETIC FIELDS

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Abstract

Seedbanking is a practice associated with heavy over-seeding to help athletic field managers sustain turf cover in high traffic scenarios and whether a true seedbank is being formed or if multiple inputs offer a source of fresh seed remains unanswered. Kentucky bluegrass was seeded at 30, 60, and 120 g m^{-2} and perennial ryegrass at 150, 300, and 450 g m^{-2}, both on bare ground, under two seeding schedules, and trafficked weekly during a US football season. Evaluations on percentage cover were made monthly during the season and emerged seedlings from plot cores were evaluated 3, 7, and 12 months after seeding to determine seedbanking potential. At the end of the traffic season, Kentucky bluegrass cover was 23.2% greater and perennial ryegrass was 10.6% greater for a single seeding compared to multiple. At 3 months after planting, multiple seedings resulted in 28.0 and 141.5 greater emerged seedlings for Kentucky bluegrass and perennial ryegrass, respectively, than single seeding. Very few seedlings emerged from cores of either species taken at 7 and 12 months after seeding. Turf managers will maximize turf cover on bare areas by seeding heavily in early fall, and can provide a fresh source of seed through the season by multiple seedings. No beneficial seedbanking ability was observed with either species.

Introduction

Seedbanking is a term often heard as a recommendation for athletic field managers to help sustain turf cover in the presence of traffic. The term is associated with heavy over-seeding, and whether a seedbank is actually being created remains unanswered (Sherratt et al., 2009). Seedbank development in turfgrass management has received attention in popular press (Stier, 2008; Sherratt et al., 2009); however, it is limited to forage, prairie, and grassland management in refereed literature (Rampton and Ching, 1966; Thompson, 1987; Cardina et al., 1996; Chauhan et al., 2006; Garrison and Stier, 2010). Hoiberg et al. (2009) conclude that additional research is needed to explore the ability of turfgrass seed to develop a beneficial seedbank over a given time period.

Anecdotal reporting of seed germinating well after a prescribed window is common in the turf industry, but again, research to prove seedbank formation in turfgrass is limited. Seedbanks are studied extensively in weed science as weeds form varying degrees of seedbanks that are necessary for species survival (Roberts, 1981; Gross and Renner, 1989; Cardina et al., 1991; Yenish et al., 1992; Cavers, 1995; Dessaint et al., 1997; Zhang et al., 1998). Annual bluegrass (*Poa annua* L.) is known for forming a dense and persistent seedbank which is responsible for its ability to reinfest areas where it has been controlled or perished (Shem-Tov and Fennimore, 2003).

Perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.), both commonly used on cool season athletic fields, have shown limited persistence in soil. Rampton and Ching (1966) showed that perennial ryegrass had very limited capacity for longevity and dormancy maintenance and suffered the most rapid deterioration of any seeds in the experiment, while Kentucky bluegrass showed promise in year one only to demonstrate a sharp decline in viability in year two. Seeds from both annual and perennial grasses can compose a large portion of seed numbers present in grasslands; however, due to synchronous germination in autumn, seeds from annual ryegrass (*Lolium multiflorum* Lam.) and perennial ryegrass make little or no contribution to the seedbank (Roberts, 1981). Given these findings, is continual over-seeding of turfgrasses really forming a seedbank, or are turf managers simply providing a constant source of new seed to germinate in bare areas (Stier, 2008).

Our objectives in this study were: 1) to determine the potential of Kentucky bluegrass and perennial ryegrass to form useful seedbanks in a trafficked athletic field scenario, 2) to determine the effect of seeding schedule (one time vs. multiple seedings) on seedbank formation and turf cover, and 3) to determine the effect of seeding rate on seedbank formation and turf cover.

Materials & Methods

This study was conducted on a Nicollet soil (fine-loamy, mixed, mesic Aquic Hapludoll) with 34 ppm P (Bray 1), 83 ppm K, pH of 6.8, and 4.0% organic matter at the Horticulture Research Station in Ames, Iowa, USA. The trial was initiated on 4 Sept 2009 and repeated on 13 Sept 2010 in an adjacent location; neither area had received any seed inputs for at least one year. Any existing vegetation on the plot areas was killed with glyphosate (Roundup®) twice; once three weeks prior to seeding and once one week prior to seeding. Dead vegetation was cleared from the plot area so seeding could occur on bare ground.

The study used a strip plot experimental design with a 2 x 3 factorial treatment structure and individual plots were 1.5 x 0.6 m^2. The two factors were seeding rate and a combination of traffic level and seeding schedule. Two traffic levels were stripped over three seeding rates within each of three replicated blocks that included separate plots for multiple and single seeding schedules; therefore, each experimental unit represented an intersection of one seeding rate and one combination of seeding schedule and traffic level (e.g. perennial ryegrass seeding rate of 150 g m^{-2} seeded once and receiving 4 passes traffic wk^{-1}).

Kentucky bluegrass '*Unique*' seeding rates were 30, 60, and 120 g m^{-2}, and perennial ryegrass '*Brightstar SLT*' seeding rates were 150, 300, and 450 g m^{-2}. The single seeding event occurred on the initial study date of each year, 4 Sept 2009 and 13 Sept 2010. Multiple seeding consisted of five seeding events each applied exactly one week apart, starting on the same day as the single seeding, concluding on 2 October in 2009 and 11 October in 2010. For each seeding rate, the total amount of seed applied in the multiple seeding schedule was equal to that of the single seeding schedule after five seedings. During each seeding event, seed was spread by hand over individual plots and immediately cleated-in with 4 passes from the traffic simulator to establish seed to soil contact. Traffic treatments consisted of 4 passes wk^{-1} (traffic) and 0 passes wk^{-1} (no traffic) for each seeding schedule. On each multiple seeding date, the "no traffic" strip was given one pass with the simulator to cleat seed into the soil, ensuring that it did not rest on the canopy. One pass with the simulator was also performed on the "no traffic" strip on the single seeding blocks to equalize traffic. After completion of multiple seeding applications on the "no traffic" strips, no further traffic was applied therein.

The entire study received 25 kg N ha^{-1} on 15 Sept and 17 Oct in 2009 and 16 Sept and 14 Oct in 2010 for a total of 50 kg N ha^{-1} per year of study. Plots were mowed twice weekly at 5 cm with clippings returned, and 25 mm of water was applied after traffic treatments through the week to promote establishment and seedling development. Because the traffic simulator performs poorly on wet soil, plots were allowed to dry over the weekend so traffic could occur on a firm and non muddy surface.

Traffic was applied with a GA-SCW simulator with cleated rollers and a differential slip action (Carrow et al., 2001) during a ten week period. A single pass of the traffic simulator was equal to operating the machine over a strip one time in one direction. The GA-SCW traffic simulator applied 6.03 cleat dents dm^{-2} in a single pass and that is equal to the number of cleat dents for one professional football game as described by Cockerham (1989). Each level of traffic was applied all at once per week and the first pass was always done in reverse and the last forward so the smooth rear roller provided a final flattening of the dimpled surface. Percentage cover data were taken in 2009 on 26 Sept, 25 Oct, and 15 Nov, and in 2010 on 30 Sept, 28 Oct, and 18 Nov with a Canon PowerShot P1 IS (Canon, USA) housed in a standardized lightbox (NextGen Research, Willamette Valley, OR, USA). Digital images were batch processed with SigmaScan Pro 5 (SPSS, Inc., Chicago, IL, USA) and data were extracted as described in Richardson et al. (2001) for percentage turf cover.

A 10 cm standard golf cup core was removed from each plot for further analysis on 5 Dec 2009, 23 Apr 2010, and 20 Sept 2010 for year one, and 12 Dec 2010, 19 Apr 2011, and 16 Sept 2011 for year two. After cores were extracted, existing vegetation on the plugs was removed if necessary with a Liscop Super-Profi 3000 sheep shear (Liscop, Germany). Once clear, the top one inch of each plug was separated, broken up by hand, and bagged for transport to the greenhouse. The broken up soil was spread to approximately 1.3 cm deep into a 20 cm diameter azalea pot atop Sunshine LC1 soilless growing mix (Sun Gro Horticulture, Alberta, Canada). Once potted, the sample was moved to a bench in the greenhouse and hand watered as needed to ensure sufficient moisture and growing conditions for germination.

Seedlings were counted often to minimize overcrowding, and during counts a seedling was removed after emergence. After all seedlings were counted and removed from a pot, soil was stirred lightly to ensure all seeds had a chance to germinate. Pots were considered exhausted of viable seed once no new seedlings germinated for two weeks after final stirring.

Data for percentage cover and cumulative seedling emergence were analyzed separately for each species and sample date with PROC MIXED in SAS Statistical Software (SAS Inc., Cary, NC) with additional random effects of year*block*seeding rate (rows within blocks and years) and year*block*schedule/traffic level (columns within blocks and years) (Philip Dixon, personal communication).

Definition of banked turfgrass seed

Although transient seedbanks are considered seeds banked for one year or less, our definition of banked turfgrass seed relates to seed that survives the initial winter after planting in the top 2.5 cm of soil. Therefore, numbers of emerged seedlings from cores of Kentucky bluegrass and perennial ryegrass at the end of the initial planting season are viewed as a baseline upon which to determine if similar numbers existed the following spring or fall. If numbers of emerged seedlings declined in the period between December of the planting year and April of the following year, we concluded that available seed died over the winter and did not bank in the context of applied turfgrass management. Further, back calculated values for seeding rate (g m^{-2}) of banked seed will be offered based on the number of seedlings that emerged from sampled cores.

Results and Discussion

Percentage cover – perennial ryegrass

Seeding rate affected perennial ryegrass cover for all sample dates, as seeding schedule and traffic level (Table 1). The two factors also interacted on each sample date (Table 1), however, this occurred as a change in magnitude with no change in order, i.e. an increase in seeding rate resulted in increased turf cover, but the magnitude of means varied with different combinations of seeding schedule and traffic level. It is expected with two seeding schedules under differing levels of traffic that there will be differences in magnitude with regard to percentage cover. Therefore, data will be presented for each main effect to simplify presentation. Similarly, there was a year*seeding schedule/traffic level interaction for each sample date (Table 1) and this can be explained by the initial seeding date relative to the first sample date. Due to inclement weather in early September 2010, the initial seeding date was nine days later than in 2009; therefore, more seed had been applied and thus emerged by the first sampling date. Again, this was a change in magnitude, not order, so data were pooled over years and will be presented as such.

Averaged over seeding rates and traffic levels, a single seeding schedule resulted in greater perennial ryegrass cover when compared to multiple seedings, regardless of traffic, on every sample date (Table 2). Turf cover was greater for a single seeding by 43.5%, 21.8%, and 10.6% in the beginning, middle, and end of the traffic season, respectively (Table 2). Although turf cover was higher with a single seeding schedule throughout the experiment, attrition caused by traffic lessened the difference by the final sample date (Table 2).

For plots receiving no traffic, a single seeding always resulted in more turf cover than multiple seedings; however, by the end of the traffic season, the difference between schedules with no traffic was smaller, indicating multiple seedings can offer similar turf cover without traffic albeit over a longer establishment period (Table 2). Under no traffic, single seeding resulted in 91.8%, 99.9%, and 97.8% turf cover in the beginning, middle, and end of the traffic period (Table 3), respectively, which was 46.0%, 17.8%, and 7.1% greater than resulting turf cover from multiple seeded plots (Table 2).

For plots receiving 4 passes wk^{-1}, a single seeding resulted in greater turf cover on each sample date when compared to multiple seedings. Single seeding resulted in 81.5%, 76.9%, and 58.5% turf cover for the beginning, middle, and end of the traffic period (Table 3), respectively, which was 41.1%, 25.7%, and 14.1% greater than resulting turf cover from multiple seeded plots during the same period (Table 2).

Increases in seeding rate resulted in increased turf cover on each sample date (Table 3). As seeding rate increased from 150 to 450 g m^{-2}, percentage turf cover increased from 52.8% to 74.9% during the beginning of the traffic season, from 67.3% to 85.4% during the middle, and 61.0% to 82.3% by the end (Table 3).

These results parallel work done by Hoiberg et al. (2009) and Minner and Valverde (2005), who found that a single seeding resulted in greater turf cover of annual and perennial ryegrass, respectively, and that increases in seeding rate above normal resulted in greater turf cover at the beginning, middle, and end of a simulated traffic period.

Percentage cover – Kentucky bluegrass

Seeding rate and seeding schedule/traffic level both affected percentage cover of Kentucky bluegrass on all sample dates; these main effects also interacted on each sample date (Table 4). Traffic treatments and seeding schedule resulted in differences of magnitude but not order, i.e., percentage cover increased with seeding rate, but the magnitude of means varied with different combinations of seeding schedule and traffic level. Any year*seeding rate or year*seed schedule/traffic level effects were also interactions of magnitude and only occurred once in the middle and end of the traffic period, respectively (Table 4).

Averaged over seeding rates and traffic levels, a single seeding provided 17.9%, 24.1%, and 23.2% greater turf cover when compared to multiple seeding for the beginning, middle, and end of the traffic period, respectively (Table 5). With no traffic, single seeding resulted in 36%, 62.3%, and 69.7% cover for the three sampling dates (Table 6), which was 26.7%, 43.6%, and 44.3% greater than multiple seeding (Table 5). Trafficked plots highlighted the inherent disadvantage of Kentucky bluegrass establishment during traffic, providing 15.0%, 8.9%, and 4.1% turf cover for the three sampling periods under single seeding, while plots seeded multiple times resulted in 5.8%, 4.4%, and 2.1% cover on the same dates (Table 6). These results coincide with those by Minner et al. (2008), who conclude that Kentucky bluegrass is not a desirable species to establish during traffic due to slow germination and maturity, and that a single seeding provides greater turf cover when compared to dividing the same amount of seed into multiple applications.

Percentage cover increased from 9.1% to 24.1% for the first sample date, from 16.9% to 29.8% for the second, and from 21.0% to 28.9% for the last sample, as seeding rate increased from 30 to 120 g m^{-2} (Table 6). An increase in seeding rate always resulted in greater turf cover; however, under the traffic conditions of this study, Kentucky bluegrass established from seed near the onset of and subject to traffic provided less than 15% cover (Table 6), making it difficult to recommend when seeding into bare ground on heavily trafficked areas. Seeding rate results for Kentucky bluegrass coincide with Minner and Valverde (2005), who conclude that due to low percentage cover of Kentucky bluegrass established from seed and subjected to traffic prior to maturity, it was difficult to predict a useful seeding rate.

Emerged seedlings from cores of perennial ryegrass

Main effect of seeding rate was present for the first sample date only, while main effect of seeding schedule/traffic level was present for the first two sample dates but not the last (Table 7). There was an interaction between seeding rate and seeding schedule/traffic level for the first sample date (Table 7), but again this was an interaction of magnitude and not order, i.e. emerged seedlings from cores increased with seeding rate but means varied with combinations of traffic level and seeding schedule. Similarly, there was a year*seeding schedule/traffic level interaction for the first sample date which also resulted from differences in magnitude (Table 7).

Averaged over traffic levels and seeding rates, multiple seeding resulted in 141.5 more emerged seedlings from sampled cores when compared to single seeding on the first sample date (Table 8). With no traffic, single seeding resulted in 3.3 emerged seedlings, while multiple seeding resulted in 199.3 (Table 9), representing equivalent seeding rates of 0.8 and 50 g m^{-2}, respectively. With traffic, single seeding had 3.1 emerged seedlings compared to 90.0 for multiple seeding (Table 9), representing equivalent seeding rates of 0.8 and 22.5 g m^{-2}, respectively.

Averaged over traffic levels and seeding rates, multiple seeding resulted in 20.4 more emerged seedlings from sampled cores than single seeding on the second sample date (Table 8). With no traffic, multiple and single seeding provided 30.8 and 5.5 emerged seedlings, respectively, representing equivalent seeding rates of 7.5 and 1.4 g m^{-2} (Table 9). Cores from plots receiving traffic resulted in 19.4 and 5.5 emerged seedlings for multiple and single seeding, respectively, and represented equivalent seeding rates of 4.9 and 1.4 g m^{-2} (Table 9).

The final sample date showed no differences among combinations of seeding schedule and traffic level (Table 9). Further, 1.2 or less seedlings emerged from all plots on this sample date (Table 9), leading us to conclude that essentially no seed was banked for an entire year under the conditions of our study.

For the December sample date, emerged seedlings increased from 30.3 to 112.8 as seeding rate increased from 150 to 450 g m^{-2} (Table 9). The effect of seeding rate on emerged seedlings was not present for the second or third sample dates (Table 7), indicating that seeding rate was a temporary effect, being more important during the traffic season than after it. This coincides with results from seeding schedule/traffic level effects that showed numbers of emerged seedlings declined sharply with time (Table 9).

Plots receiving traffic resulted in fewer emerged seedlings from cores than those without traffic, which may indicate that the thinning effect of traffic exhausted available seed sooner than turf not subject to traffic. Additionally, a single seeding at the rates used in this study appeared to exhaust available seed sooner than multiple seedings, leading us to believe that multiple inputs later in the season are what resulted in higher numbers of emerged seedlings from cores in those plots. This addresses the question put forth by Sherratt, et al. (2009) of whether a constant seed source or true seedbank is responsible for perpetuating turf cover when turf managers practice heavy over-seeding. What appeared to be a substantial amount of seed left in cores at the end of the planting season did not carry over to the following year, and by one year after planting, no seed was available for growth, indicating a short window of viability in the top 2.5 cm of the soil profile where soil turnover results from traffic. These findings are supported by Rampton and Ching (1966) who showed that perennial ryegrass seeds recovered from 2.5 cm depth had practically negligible germination after being buried for one year and by Roberts (1981) who found that due to synchronous germination in autumn, perennial ryegrass seed made little or no contribution to the seedbank.

Emerged seedlings from cores of Kentucky bluegrass

Seeding rate and seeding schedule/traffic level affected emerged seedlings of Kentucky bluegrass on the first sample date only and no interactions occurred on any sample date (Table 10).

On the first sample date, mean emerged seedlings increased from 13.0 to 23.4 as seeding rate increased from 30 to 60 g m^{-2} (Table 12). Unlike perennial ryegrass, further increases in Kentucky bluegrass seeding rate did not result in more emerged seedlings (Table 11).

With traffic, multiple seeding resulted in 31.4 more emerged seedlings than single seeding on the first sample date (Table 11). There was no effect of seeding schedule and traffic level on seedling emergence for the second or third sample dates, indicating that any seed in the top inch of soil is either quickly exhausted during the traffic season or died during winter.

With no traffic, multiple seeding resulted in 35.7emerged seedlings on the first sample date, representing an equivalent seeding rate of 9 g m^{-2}, while a single seeding under no traffic resulted in 11.2 emerged seedlings on the same sample date and represented an equivalent seeding rate of 3 g m^{-2} (Table 12). As with plots subject to traffic, there was no difference between seeding schedules for the last two sample dates for non-trafficked plots (Table 12).

Multiple inputs appeared to be responsible for higher numbers of emerged seedlings from cores sampled in December of the planting season. These findings are similar to perennial ryegrass results as emerged seedling numbers declined to near 0 when sampled beyond December of the planting year, indicating that seed did not survive the winter, and therefore, did not bank based on our definition. Under the seeding schedules and rates used in this study, our findings demonstrate an even shorter window of seed viability for Kentucky bluegrass than Rampton and Ching (1966) who found that recovered Kentucky bluegrass seeds buried at 2.5 cm in mesh bags exhibited 2.9% germination in year one and 0% in year two.

Although transient seedbanks are defined as those viable for one year or less, our conclusion is that multiple inputs of seed were responsible for higher numbers of seedlings emerged, representing available seed in December of the planting year. With the reduction in numbers of emerged seedlings sampled 7 and 12 months after sowing, it is clear that some seed that was available during the first sample date, was not for the last two. As our final inputs of seed occurred in the first two weeks of October, it is possible that the final planting dates resulted in germination into winter, resulting in winter kill. Minner and Valverde (2008) found that mid October was the least effective time to overseed in the north-central region of the United States and Larsen and Bibby (2005) showed that minimum temperatures for Kentucky bluegrass and perennial ryegrass germination were 2.6°C and 3.6°C, respectively. However, large amounts of seed would not likely germinate in December in central Iowa.

Conclusions

Kentucky bluegrass is not recommended for seeded establishment in fall immediately prior to the onset of traffic due to slow germination and establishment. Despite multiple seedings not providing as much turf cover in either species, it was clear that multiple inputs did result in seed that is available for germination at the end of the traffic season, leading us to recommend a multi-faceted approach of one single, heavy seeding early in the season, followed by multiple seeding events throughout the traffic season to provide a fresh source of seed as turf cover thins from traffic. However, turf managers should not expect large numbers of available seed in the spring following planting, i.e. a true seedbank as defined in our experiment is not being formed when these species are seeded to bare ground.

Further research is needed to determine seedbanking potential under established, mature turf cover, and whether seed is banked deeper in the profile was beyond the scope of this project, as it would not likely contribute cover without some mechanical turnover to place seed in a germinable position, disrupting the playing surface.

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Table 1. ANOVA for percentage cover of perennial ryegrass seeded at three rates, two seeding schedules, and subjected to two levels of traffic evaluated during an autumn traffic season in 2009 and 2010.

Source	df	Simulated traffic period		
		Beginning	Middle	End
2009		26 Sept.	25 Oct.	15 Nov.
2010		30 Sept.	28 Oct.	18 Nov.
Seedrate	2	**	**	**
Seed schedule/traffic	3	**	**	**
Seedrate*Seed schedule/traffic	6	*	**	**
Year*Seedrate	2	NS	NS	NS
Year*Seed schedule/traffic	3	**	**	**

* Significant at 0.05 probability level
** Significant at 0.01 probability level

Table 2. Contrasts and estimated differences among means of perennial ryegrass percentage cover subjected to simulated traffic during an autumn establishment period. The first level of contrasts are between combinations of seeding schedule and traffic level, the second between different seeding rates used in this study.

Source	Simulated traffic period					
	Beginning		Middle		End	
2009	26 Sept.		25 Oct.		15 Nov.	
2010	30 Sept.		28 Oct.		18 Nov.	
	Differences in percentage cover					
Contrast (seeding schedule-traffic level)	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
Single vs. Multiple seeding	43.5	**	21.8	**	10.6	**
Single-0 vs. Multiple-0	46.0	**	17.8	**	7.1	**
Single-4 vs. Multiple-4	41.1	**	25.7	**	14.1	**
Multiple-0 vs. Multiple-4	5.4	*	30.9	**	46.3	**
Single-0 vs Single-4	10.3	**	23.1	**	39.3	**
$LSD_{(0.05)}$	**4.8**		**3.8**		**3.2**	
Contrast (seeding rate in g m^{-2})	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
300 vs 150	14.1	**	12.5	**	14.2	**
450 vs 300	8.0	**	5.5	**	7.1	**
450 vs 150	22.1	**	18.0	**	21.3	**
$LSD_{(0.05)}$	**4.7**		**3.5**		**3.6**	

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 3. Mean percentage turf cover of perennial ryegrass under two levels of traffic, two seeding schedules, and three seeding rates. Means are separated by Fisher's protected least significant difference with an alpha level of 0.05.

Source	Simulated traffic period		
	Beginning	Middle	End
2009	26 Sept.	25 Oct.	15 Nov.
2010	30 Sept.	28 Oct.	18 Nov.
Seeding schedule-traffic level	Percentage turf cover		
Single-0	91.8	99.9	97.8
Single-4	81.5	76.9	58.5
Multiple-0	45.8	82.1	90.7
Multiple-4	40.4	51.2	44.4
$LSD_{(0.05)}$	**4.8**	**3.8**	**3.2**
Seeding rate (g m^{-2})			
150	52.8	67.3	61.0
300	67.0	79.9	75.2
450	74.9	85.4	82.3
$LSD_{(0.05)}$	**4.7**	**3.5**	**3.6**

Table 4. ANOVA for percentage cover of Kentucky bluegrass seeded at three rates, two seeding schedules, and subjected to two levels of traffic evaluated during an autumn traffic season in 2009 and 2010.

Source	df	Simulated traffic period		
		Beginning	Middle	End
2009		26 Sept.	25 Oct.	15 Nov.
2010		30 Sept.	28 Oct.	18 Nov.
Seedrate	2	**	**	**
Seed schedule/traffic	3	**	**	**
Seedrate*Seed schedule/traffic	6	**	**	**
Year*Seedrate	2	NS	*	NS
Year*Seed schedule/traffic	3	NS	NS	*

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 5. Contrasts and estimated differences among means of Kentucky bluegrass percentage cover subjected to simulated traffic during an autumn establishment period. The first level of contrasts are between combinations of seeding schedule and traffic level, the second between different seeding rates used in this study.

Source	Simulated traffic period					
	Beginning		Middle		End	
2009	26 Sept.		25 Oct.		15 Nov.	
2010	30 Sept.		28 Oct.		18 Nov.	
	Differences in percentage cover					
Contrast (seeding schedule-traffic level)	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
Single vs. Multiple seeding	17.9	**	24.1	**	23.2	**
Single-0 vs. Multiple-0	26.7	**	43.6	**	44.3	**
Single-4 vs. Multiple-4	9.2	*	4.5	NS	2.0	NS
Multiple-0 vs. Multiple-4	3.6	NS	14.2	**	23.3	**
Single-0 vs Single-4	21.0	**	53.3	**	65.6	**
LSD$_{(0.05)}$	**7.5**		**4.6**		**3.2**	
Contrast (seeding rate in g m^{-2})	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
60 vs 30	7.3	**	7.1	**	5.0	**
120 vs 60	7.8	**	5.8	**	3.0	*
120 vs 30	15.0	**	12.9	**	8.0	**
LSD$_{(0.05)}$	**2.3**		**2.7**		**2.4**	

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 6. Mean percentage turf cover of Kentucky bluegrass under two levels of traffic, two seeding schedules, and three seeding rates. Means are separated by Fisher's protected least significant difference with an alpha level of 0.05.

Source	Simulated traffic period		
	Beginning	Middle	End
2009	26 Sept.	25 Oct.	15 Nov.
2010	30 Sept.	28 Oct.	18 Nov.
Seeding schedule-traffic level	Percentage turf cover		
Single-0	36.0	62.3	69.7
Single-4	15.0	8.9	4.1
Multiple-0	9.3	18.7	25.3
Multiple-4	5.8	4.4	2.1
$LSD_{(0.05)}$	**7.5**	**4.6**	**3.2**
Seeding rate (g m^{-2})			
30	9.1	16.9	21.0
60	16.4	24.0	26.0
120	24.1	29.8	28.9
$LSD_{(0.05)}$	**2.3**	**2.7**	**2.4**

Table 7. ANOVA for emerged seedlings from 10 cm x 2.5 cm cores of perennial ryegrass seeded at three rates, two seeding schedules, and subjected to two levels of traffic evaluated during an autumn traffic season in 2009 and 2010.

Source	df	Sample date		
		First	Second	Third
2009-10		5 Dec. 2009	23 Apr. 2010	20 Sept. 2010
2010-11		12 Dec. 2010	19 Apr. 2011	16 Sept. 2011
Seedrate	2	**	NS	NS
Seed schedule/traffic	3	**	**	NS
Seedrate*Seed schedule/traffic	6	**	NS	NS
Year*Seedrate	2	NS	NS	NS
Year*Seed schedule/traffic	3	**	NS	NS

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 8. Contrasts and estimated differences among means of emerged seedlings from 10 cm x 2.5 cm cores of perennial ryegrass subjected to simulated traffic during an autumn establishment period. The first level of contrasts are between combinations of seeding schedule and traffic level, the second between different seeding rates used in this study.

Source	Sample date					
	First		Second		Third	
2009-10	5 Dec. 2009		23 Apr. 2010		20 Sept. 2010	
2010-11	12 Dec. 2010		19 Apr. 2011		16 Sept. 2011	
	Differences in emerged seedlings					
Contrast (seeding schedule-traffic level)	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
Muliple vs. Single seeding	141.5	**	20.4	**	0.1	NS
Multiple-0 vs. Single-0	196.1	**	25.3	**	0.4	NS
Multiple-4 vs. Single-4	86.9	**	15.6	**	0.6	NS
Multiple-0 vs. Multiple-4	109.3	**	11.4	**	0.4	NS
Single-0 vs Single-4	NS	NS	NS	NS	0.6	NS
$LSD_{(0.05)}$	**23.4**		**4.2**		**NS**	
Contrast (seeding rate in g m^{-2})	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
300 vs 150	48.3	**	3.3	NS	0.2	NS
450 vs 300	34.1	*	1.4	NS	0.5	NS
450 vs 150	82.5	**	4.7	NS	0.6	NS
$LSD_{(0.05)}$	**24.7**		**NS**		**NS**	

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 9. Mean emerged seedlings from perennial ryegrass 10 cm x 2.5 cm cores under two levels of traffic, two seeding schedules, and three seeding rates. Means are separated by Fisher's protected least significant difference with an alpha level of 0.05.

Source	Sample date		
	First	Second	Third
2009-10	5 Dec. 2009	23 Apr. 2010	20 Sept. 2010
2010-11	12 Dec. 2010	19 Apr. 2011	16 Sept. 2011
Seeding schedule-traffic level	Emerged seedlings		
Single-0	3.3	5.5	1.2
Single-4	3.1	3.8	0.6
Multiple-0	199.3	30.8	0.8
Multiple-4	90.0	19.4	1.2
$LSD_{(0.05)}$	**23.4**	**4.2**	**NS**
Seeding rate (g m^{-2})			
150	30.3	12.2	0.7
300	78.7	15.5	0.9
450	112.8	16.9	1.3
$LSD_{(0.05)}$	**24.7**	**NS**	**NS**

Table 10. ANOVA for emerged seedlings from 10 cm x 2.5 cm cores of Kentucky bluegrass seeded at three rates, two seeding schedules, and subjected to two levels of traffic evaluated during an autumn traffic season in 2009 and 2010.

Source	df	Sample date		
		First	Second	Third
2009-10		5 Dec. 2009	23 Apr. 2010	20 Sept. 2010
2010-11		12 Dec. 2010	19 Apr. 2011	16 Sept. 2011
Seedrate	2	**	NS	NS
Seed schedule/traffic	3	**	NS	NS
Seedrate*Seed schedule/traffic	6	NS	NS	NS
Year*Seedrate	2	NS	NS	NS
Year*Seed schedule/traffic	3	NS	NS	NS

* Significant at 0.05 probability level
** Significant at 0.01 probability level.

Table 11. Contrasts and estimated differences among means of emerged seedlings from 10 cm x 2.5 cm cores of Kentucky bluegrass subjected to simulated traffic during an autumn establishment period. The first level of contrasts are between combinations of seeding schedule and traffic level, the second between different seeding rates used in this study.

Source	Sample date					
	First		Second		Third	
2009-10	5 Dec. 2009		23 Apr. 2010		20 Sept. 2010	
2010-11	12 Dec. 2010		19 Apr. 2011		16 Sept. 2011	
	Differences in emerged seedlings					
Contrast (seeding schedule-traffic level)	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
Muliple vs. Single seeding	28.0	**	2.0	NS	0.3	NS
Multiple-0 vs. Single-0	24.5	**	3.4	NS	0.7	NS
Multiple-4 vs. Single-4	31.4	**	0.6	NS	0.1	NS
Multiple-0 vs. Multiple-4	0.3	NS	3.2	NS	1.1	NS
Single-0 vs Single-4	6.7	NS	0.4	NS	0.4	NS
$LSD_{(0.05)}$	**16.1**		**NS**		**NS**	
Contrast (seeding rate in g m^{-2})	Estimate	Pr > t	Estimate	Pr > t	Estimate	Pr > t
60 vs 30	10.5	**	0.8	NS	0.3	NS
120 vs 60	5.8	NS	0.2	NS	0.5	NS
120 vs 30	16.3	**	0.6	NS	0.3	NS
$LSD_{(0.05)}$	**6.5**		**NS**		**NS**	

* Significant at 0.05 probability level

** Significant at 0.01 probability level.

Table 12. Mean emerged seedlings from Kentucky bluegrass 10 cm x 2.5 cm cores under two levels of traffic, two seeding schedules, and three seeding rates. Means are separated by Fisher's protected least significant difference with an alpha level of 0.05.

Source	Sample date		
	First	Second	Third
2009-10	5 Dec. 2009	23 Apr. 2010	20 Sept. 2010
2010-11	12 Dec. 2010	19 Apr. 2011	16 Sept. 2011
Seeding schedule-traffic level	Emerged seedlings		
Single-0	11.2	1.0	2.4
Single-4	4.6	0.6	2.0
Multiple-0	35.7	4.4	3.1
Multiple-4	36.0	1.2	1.9
$LSD_{(0.05)}$	**16.1**	**NS**	**NS**
Seedrate (g m^{-2})			
30	13.0	1.3	2.3
60	23.4	2.1	2.1
120	29.3	1.9	2.6
$LSD_{(0.05)}$	**6.5**	**NS**	**NS**

FATE OF KENTUCKY BLUEGRASS AND PERENNIAL RYEGRASS SEED SOWN AT CLEATED-IN DEPTH

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Abstract

Kentucky bluegrass and perennial ryegrass seeds have shown limited persistence in soil. Building a seedbank with these species on athletic fields has been a recommendation for athletic field managers, normally involving heavy over-seeding and relying on player's cleated shoes to establish seed to soil contact for germination. Our study examined the fate of seeds sown at 2.5 cm in autumn by filling and extracting mesh bags filled with the respective species at 3, 7, and 12 months after sowing. After retrieval, seeds that had not germinated were further investigated by allowing a secondary germination period in a germination box, and lastly via forceps test and tetrazolium staining of non-germinated seed. Kentucky bluegrass had initial germination of 86% and of remaining seeds, most were dead and very few exhibited secondary germination. Perennial ryegrass had initial germination of 89% and of remaining seeds, most were dead and very few, with the exception of one retrieval date, exhibited secondary germination. When planted under no cover, most Kentucky bluegrass and perennial ryegrass germinates at 2.5 cm depth and of that left over, most were dead.

Introduction

Seeds of cool season turfgrass species used in athletic fields, perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.) have shown limited persistence in soil. Rampton and Ching (1966) showed that perennial ryegrass had very limited capacity for longevity and dormancy maintenance and suffered the most rapid deterioration of any seeds in their experiment, while Kentucky bluegrass showed promise in the first year only to demonstrate a sharp decline in viability in the second year. Seeds from both annual and perennial grasses can compose a large portion of seed numbers present in grasslands; however, due to synchronous germination in autumn, seeds from *Lolium multiflorum* and *Lolium perenne* make little or no contribution to the seedbank (Roberts, 1981). Garrison and Stier (2010) found that Kentucky bluegrass seed colonies declined rapidly or ceased to exist when put in competition with existing prairie seedbanks.

Seed size and shape have been related to seedbank potential as large seeds are less likely to infiltrate soil, having less chance of accessing small openings therein (Bekker et al., 1998). Similarly, relatively larger seeds from *Festuca* spp. and *Lolium perenne* are less prone to earthworm ingestion when compared to smaller seeds from *Poa* spp. and *Agrostis* spp., and are therefore less likely to form seedbanks than smaller seeded species (Thompson, 1987) as ingestion from earthworms is important for both burial of seeds and subsequent return to the soil surface via casting. Further, Thompson (1987) concludes that characteristics such as small size, compact shape, and lack of awns or hairs will predispose them to ingestion.

Anecdotal reporting of seed germinating well after a prescribed window is commonplace in the turf industry, but applied research to prove seedbank formation with annual and perennial turfgrasses is limited. Seedbanks are studied extensively in weed science as weeds form varying degrees of seedbanks that are necessary for the species survival (Roberts, 1981; Gross and Renner, 1989; Cardina et al., 1991; Yenish et al., 1992; Cavers, 1995; Dessaint et al., 1997; Zhang et al., 1998). Seedbanks in grasses are not entirely alien, however. Annual bluegrass (*Poa annua* L.), although a weedy species, is known for forming a dense and persistent seedbank which is responsible for its ability to reinfest areas where it has been controlled or perished (Shem-Tov and Fennimore, 2003).

One potential limitation for turfgrass seedbank formation is the position of seeds as they are applied and worked into the soil profile. Seeds are distributed in different strata of soil by processes of broadcasting, cleating-in, and cultivation; depth of distribution is related to depth of cleat or cultivation penetration. “Cleating-in” is a practice whereby sports field managers broadcast seed over high traffic areas and allow the action of player’s cleated shoes to press seed into the surface, creating seed to soil contact necessary for germination. Only seeds that can obtain requisite moisture, soil contact, nutrients, and sunlight are in prime position to germinate and those that are not may eventually be brought into the necessary position by continual thinning of existing grass and turnover of the soil.

Depth of cultivation practices may differ depending on the time of year, reason for cultivation, and timing of cultivation relative to seeding. Similarly, the length of cleats worn by athletes can range from 1.3 to 1.9 cm, and if cleating-in is the only method utilized by turf managers to incorporate seed into soil, it can be assumed that the majority of seeds will travel no deeper than 2.5 cm in the soil. Hoiberg et al. (2009) concludes that additional research is needed to explore the ability of turfgrass seed to develop a beneficial seedbank over a given time period.

Our objectives were: 1) to monitor long term viability, i.e. seedbanking potential of perennial ryegrass and Kentucky bluegrass through one year after seeding and 2) to determine if perennial ryegrass and Kentucky bluegrass seeds exhibit different longevity in soil when buried at 2.5 cm.

Materials and Methods

This study was conducted on a Nicollet soil (fine-loamy, mixed, mesic Aquic Hapludoll) with 34 ppm P (Bray1), 83 ppm K, pH of 6.8, and 4.0% organic matter at the Horticulture Research Station in Ames, Iowa, USA. The trial was initiated on 23 Sept 2009 and 16 Sept 2010 on a separate location within the same plot area.

Kentucky bluegrass '*Unique*' and perennial ryegrass '*Brightstar SLT*' were individually seeded into custom made nylon mesh bags measuring 10 cm diameter, with a mesh size of 600 micron, which was small enough to prevent seed escape and to allow water permeability. Each bag contained 400 seeds (Rampton and Ching, 1966) and represented an equivalent seeding rate of 10 g m^{-2} for Kentucky bluegrass and 100 g m^{-2} for perennial ryegrass, both within recommended seeding rates (Minner et al. 2008; Madison, 1966). To make the bags, two pieces of mesh were cut out using a 10 cm template and fused together using heat to seal the two halves together, preventing seed escape. When the bags were 90% sealed, a glass funnel was inserted into the small opening, seed was funneled in and the remainder of the bag was sealed.

Once sealed, the bags were buried exactly 2.5 cm deep in the middle of 60 cm^2 plots. A standard 10 cm golf course cup cutter was used to remove a plug approximately 10 cm deep, after which a carpenter square was used to mark exactly 2.5 cm below the plug surface. After marking, a large knife was used to separate the top 2.5 cm of the plug from the bottom, which was then replaced in the void, the seed bag placed on top of it, and the top 2.5 of the plug placed on the seed bag to complete the process. A light tamping of the plug returned it to its previous position in the soil. Seed bags were left undisturbed until retrieval dates of 3 Dec 2009, 8 Apr

2010, and 2 Sept 2010 for year one and 5 Dec 2010, 11 Apr 2011, and 4 Sept 2011 for year two. On each date, three bags for each species were retrieved for analysis.

After retrieval, seed bags were carefully opened and contents relocated onto a plastic tray. Seeds were counted and discarded if germination had occurred (i.e. the presence of a root and/or a shoot). In most cases, it was obvious which seeds had germinated, however, it was necessary to examine some under a microscope. Seeds not showing signs of germination were isolated and transplanted to a germination box on blotter paper. Once inside the germination box, seeds were kept moist with a spray bottle, kept in a greenhouse, and allowed 28 days to germinate. Seeds that germinated were counted and seeds that did not germinate in the boxes were further investigated with forceps testing (Buhler et al., 2001; Borza et al., 2007) to exclude dead seeds before tetrazolium staining (ISTA, 1985) to determine viability.

The experimental design was a randomized complete block with three replications. Initial germination count (seeds that germinated between planting and retrieval), post retrieval germination count (seeds germinating after retrieval), and tetrazolium staining non-germinated seeds were recorded for each sample to determine seedbanking ability and viability. Data were analyzed separately for each sample date and species using PROC ANOVA of the SAS software, Version 9.1.3 of the SAS System for Windows (SAS Institute, 2002-2003).

Results and Discussion

Kentucky bluegrass

Initial germination differed depending on retrieval date (Table 1). Further, there was no year*sample interaction (Table 1), so data were pooled over years. Sample date did not impact secondary germination, dead seeds, or viable seeds and there were no interactions of year*sample, so data for these variables were also pooled over years (Table 1).

For samples collected in December, three months after sowing, initial germination differed from samples collected in April and September of the year following sowing, which did not differ (Table 2). Initial germination was 327 of 400 (82%) for the first retrieval, 355 of 400 (89%) for the second, and 346.8 of 400 (87%) for the last, all of which were near the labeled germination of 85%. This may indicate that there were some seeds available for germination after the first sample date as initial germination increased by April of the following year. No further increases in initial germination were observed one year after sowing (Table 2).

Secondary germination yielded 0.5, 0.7, and 0.2 seeds germinated for December, April, and September retrieval dates, respectively, and were not different (Table 2). Dead seed numbers were 71.5, 44.2, and 52.8 for December, April, and September retrieval dates, respectively and did not differ (Table 2). Lastly, viable seed numbers were 1.0, 0.2, and 0.2 for the same retrieval dates and did not differ (Table 2). Under the conditions of this study, most seed germinated, and although it was confined to the seed bags, a high percentage of Kentucky bluegrass seed germinated at 2.5 cm depth and could contribute to a wear tolerant stand. From seed left after initial germination, very little exhibited secondary germination or to retained viability. Our findings parallel those from Garrison and Stier (2010) who found that Kentucky bluegrass seed bags planted in a similar manner quickly declined or ceased to exist within a year.

Perennial ryegrass

There was a year*sample interaction for secondary germination, so data will be presented separately for 2009 and 2010 to examine differences (Table 1). There was no difference in initial germination, dead seeds, or viable seeds between retrieval dates, and no year*sample interactions, so data were pooled over years and will be presented as such for those variables (Table 1).

Initial germination was 352.8 of 400 (88%), 358.2 of 400 (90%), and 359.2 of 400 (90%) for December, April, and September retrieval dates, respectively, and did not differ (Table 2). Further, they were in accordance with the label, which claimed 90% germination. Dead seeds numbered 35.3, 40.0, and 40.5 for the same retrieval dates, respectively, and did not differ; viable seed numbers were 0.2, 0.3, and 0.2 for the same dates and also did not differ (Table 2).

Secondary germination of perennial ryegrass seeds differed depending on retrieval date and year. In year one, secondary germination yielded 1.3, 0, and 0 seedlings for December, April, and September retrieval dates, respectively, while in the second year, secondary germination yielded 22.0, 3.0, and 0.3 seedlings for the same retrieval dates (Table 3). The December retrieval date in year two was different from all other dates in the study and caused the year*sample interaction. Our speculation is that seeds in the perennial ryegrass mesh bags were more tightly grouped when they were buried and the resultant crowding of seedlings may have prevented some seeds from germinating initially.

Our findings on secondary germination and long term viability of perennial ryegrass are similar to those from Kentucky bluegrass; most seeds germinated in the first three months after sowing, and from those left over, most were dead or non-viable. These findings are supported by Rampton and Ching (1966) who found that perennial ryegrass had very limited capacity for longevity and Roberts (1981) who found that seeds from *Lolium perenne* make little or no contribution to the seedbank due to synchronous germination in autumn. Further, our findings show that there was no preferential seedbanking of Kentucky bluegrass over perennial ryegrass, as both species had similar numbers in all categories, despite a difference in seed size, downplaying the notion that smaller seeds may be more favorable for seedbank formation (Thompson, 1987).

With a single seeding in September, most Kentucky bluegrass and perennial ryegrass seed germinates, and of that left over, very little exhibited long term viability, i.e. seedbanking ability, when sown under bare ground at a depth of 2.5 cm, a similar depth resulting from being cleated-in by foot traffic. Further research is needed to determine if a similar seeding schedule could result in banked seed when planted below existing turf cover.

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Table 1. ANOVA for initial germination, secondary germination, dead seeds, and viable seeds of Kentucky bluegrass and perennial ryegrass sown in Sept 2009 and 2010 and recovered 3, 7, and 12 months after sowing.

Source	df	Initial germination	Secondary germination	Dead	Viable
		Kentucky bluegrass			
Sample	2	*	NS	NS	NS
Year*Samp	2	NS	NS	NS	NS
		Perennial ryegrass			
Sample	2	NS	NS	NS	NS
Year*Samp	2	NS	**	NS	NS

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

Table 2. Mean separation for initial germination, secondary germination, dead seeds, and viable seeds of Kentucky bluegrass and perennial ryegrass sown in autumn 2009 and 2010 and recovered 3, 7, and 12 months after sowing. Means are averaged over three replications and two years of the study and are separated by Fisher's least significant difference with α = 0.05.

	Kentucky bluegrass seeds			
Retrieval Date	Initial germination	Secondary germination	Dead	Viable
Dec 2009/2010	327.0	0.5	71.5	1.0
Apr 2010/2011	355.0	0.7	44.2	0.2
Sept 2010/2011	346.8	0.2	52.8	0.2
$LSD_{(0.05)}$	**18.6**	**NS**	**NS**	**NS**
	Perennial ryegrass seeds			
Dec 2009/2010	352.8	11.7	35.3	0.2
Apr 2010/2011	358.2	1.5	40.0	0.3
Sept 2010/2011	359.2	0.2	40.5	0.2
$LSD_{(0.05)}$	**NS**	**NS**	**NS**	**NS**

Table 3. Means for initial germination, secondary germination, dead seeds, and viable seeds of perennial ryegrass sown on 23 Sept 2009 and 16 Sept 2010 and recovered three times over the year following sowing. Means result from three replications.

Year (sowing date)	Retrieval date and mean seeds		
Year 1 (23 Sept '09)	*3 Dec '09*	*8 Apr '10*	*2 Sept '10*
Initial germination	352.0	365.7	360.7
Secondary germination	1.3	0.0	0.0
Dead	46.3	34.3	39.3
Viable (TZ test)	0.3	0.0	0.0
Year 2 (16 Sept '10)	*5 Dec '10*	*11 Apr '11*	*4 Sept '11*
Initial germination	353.7	350.7	357.7
Secondary germination	22.0	3.0	0.3
Dead	24.3	45.7	41.7
Viable (TZ test)	0.0	0.7	0.3

NITROGEN BASED ESTABLISHMENT OF KENTUCKY BLUEGRASS AND PERENNIAL RYEGRASS IN ATHLETIC FIELDS

To be submitted to *Crop Science* upon completion of the project

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ADDITIONAL INDEX WORDS. cool season athletic fields, fertility, spring establishment, fall establishment

Abstract

Nitrogen is required and applied in the largest amount of any nutrient on turfgrass and although overarching recommendations exist, nitrogen programs on heavily trafficked areas remain empirical. Our study examined the potential of multiple, light applications of urea during both spring and fall establishment of Kentucky bluegrass and perennial ryegrass from bare ground to rapidly produce aboveground biomass. Nitrogen rates ranged from 100 – 400 kg ha^{-1} in 2010 and from 0 – 400 kg ha^{-1} in 2011; each rate was divided into eight, weekly, equal applications. Spring applications were followed by a hardening off period prior to simulated traffic, while fall applications continued into the traffic season. Nitrogen effects were masked by excessive seeding rates in 2010, so rates were lowered for the 2011 study. For spring established turf in 2011, rates of 300 – 400 kg total N ha^{-1} provided the best color and most turf cover in both species and did not reduce traffic tolerance. For fall established turf in 2011, increases above 100 kg total N ha^{-1} generally resulted in decreased color and cover, highlighting differences in seasonal nitrogen usage patterns. Further, fall established Kentucky bluegrass seeded near onset of traffic resulted in low turf cover and is not recommended in such scenarios.

Introduction

Nitrogen is the most abundantly required and applied nutrient in turfgrass management and is high on the list of important cultural practices in establishment and maintenance of quality turfgrass (Turner and Hummel, 1992). Nitrogen influences growth of turfgrass tissues, increasing rate of shoot and root growth as nitrogen rate increases; however, this response will reach a point where carbohydrate availability for protein synthesis becomes limiting, causing suppression of root growth and carbohydrate reserve, while shoot growth continues (Beard, 1973). Canaway (1984) found rapid initial increase in aboveground biomass, followed by a leveling off and eventual decline at very high levels of nitrogen, which he concludes may be caused by increased moisture content of tissues and deceases in total cell wall constituents. Nitrogen fertilization has been shown to improve wear tolerance up to a threshold (Leyer and Skirde, 1980), at which aforementioned factors can result in decreased wear tolerance (Beard, 1973; Canaway, 1984). Canaway (1984) found that the optimum level of nitrogen to maximize wear tolerance in perennial ryegrass was 200 – 300 kg N ha^{-1} yr^{-1}. Therefore, nitrogen fertility programs are designed to maintain a level of nitrogen such that shoot growth will not supersede root growth and development.

Canaway (1983) concluded that aboveground biomass appears to be the most important single variable in relation to shear strength and ball bounce resilience of athletic fields prior to wear. Although increased nitrogen has been shown to decrease wear tolerance, it may be possible to increase nitrogen during establishment to increase biomass, followed by a hardening off period prior to traffic, possibly circumventing said negative effects.

Nitrogen sources exist in many forms, which differ in release mechanisms. The lowest cost nitrogen source for turfgrass professionals is urea (46-0-0), which is commonly used on turfgrass. Urea is highly soluble in water and is characterized by a quick release of short duration, leaching tendency, and foliar burn potential (Beard, 1973). For these reasons, urea based nitrogen programs should include multiple, light applications to minimize losses (Turner and Hummel, 1992). Further, urea should be followed closely by irrigation or rain to minimize volitalization (Watson, 1984).

Historically, nitrogen fertility programs included heavy spring fertilization, little or no nitrogen applied in the summer, followed by moderate applications in fall (Christians, 2007). This method can exhaust carbohydrate reserves before summer stress, resulting in late summer deterioration before nitrogen applications resume in fall. Currently, fertility programs include lighter applications in spring to minimize carbohydrate exhaustion, as-needed applications in summer, and returning to higher levels in fall (Christians, 2007). Turner and Hummel (1992) conclude that due to unreliable soil testing for nitrogen, recommendations remain largely empirical. Further, continued advances in cultivars and intensifying use of turfgrass species have altered traditional management practices (Sorochan et al., 2005). Therefore, what works for one scenario may not be applicable to another, particularly when usage patterns differ. Multiple, light applications of fertilizer are crucial for seedlings to ensure that nitrogen is adequate for growth and development, but not at rates that will cause leaf burn or restricted growth of roots and lateral shoots (Turgeon, 2005).

Increasing nitrogen to speed establishment is not new. Hummel (1980) reported quicker establishment and darker color of Kentucky bluegrass (*Poa pratensis* L.) with 97 kg N ha^{-1} when compared to 48 kg N ha^{-1}. Similarly, Madison (1962) concluded that nitrogen fertilizer increased population density without greatly affecting individual plant size. Beard (1973) indicates that nitrogen stimulates shoot growth causing an increase in tissue hydration level and that recuperative ability is enhanced by moderate nitrogen levels; further, he states that a relative rapid shoot growth rate is desirable on sports turfs subject to traffic stress and that nutritional requirements are greater during establishment. Still, optimum nitrogen rates during establishment of Kentucky bluegrass and perennial ryegrass (*Lolium* perenne L.) on athletic fields to maximize turf cover have not yet been determined. Application timing and schedule relative to traffic will be an important consideration as applications made too near traffic may result in highly succulent turfgrass susceptible to attrition. On the other hand, nitrogen applied in advance of traffic could speed establishment and increase turf cover. If combined with a period of hardening off, resulting turf could be ready for cleated wear before fields following a more traditional, year round nitrogen fertility program.

The objectives of our study were: 1) to determine if increased rates of nitrogen over a prescribed period could speed establishment of Kentucky bluegrass and perennial ryegrass, 2) to evaluate how different nitrogen rates during establishment affect subsequent traffic tolerance, and 3) to determine how planting season is affected by increased nitrogen during establishment.

Materials and Methods

This study was conducted at the Iowa State University Horticulture research station in Ames, Iowa, USA on a Nicollet soil (fine-loamy, mixed, mesic Aquic Hapludoll) with 34 ppm P (Bray1), 83 ppm K, pH of 6.8, and 4.0% organic matter in 2010 and moved in 2011 to an area with the same soil characteristics, but topdressed with 1.5 cm of sand yearly for the previous three years. The trial was initiated on 19 April for spring establishment and 13 September for fall establishment in 2010. In 2011, spring establishment was initiated on 10 May and fall establishment on 31 August. To prepare plots for seeding, glyphosate (Roundup®) was applied two weeks prior to seeding dates; dead biomass was removed by hand raking after loosening with a Billy Goat PR550H power rake (Billy Goat Industries, Lee's Summit, MO, USA).

The study used a strip plot experimental design with a 3 x 4 factorial treatment structure in 2010 and a 3 x 5 structure in 2011 with individual plot size of 1.5 x 0.6 m^2 in both years. The two main factors were traffic level and nitrogen rate. Three traffic levels were used for both years and stripped across four and five rates of nitrogen, in 2010 and 2011, respectively, and replicated in three blocks. Traffic levels consisted of 0, 4, or 8 passes of traffic wk^{-1}, which were applied all on one day every week, and nitrogen levels consisted of 100, 200, 300, or 400 kg total N ha^{-1} applied over the course of eight weeks in 2010 (e.g. 100 kg N ha^{-1} was divided into eight weekly applications of 12.5 kg N ha^{-1}). In 2011, an additional nitrogen treatment was added of 0 kg total N ha^{-1}, but all nitrogen treatments followed the same application structure from 2010. Nitrogen applications began one week after seeding for both years and seasons and were watered in by hand to prevent volatility loss.

In 2010, Kentucky bluegrass was seeded at 25 g m^{-2} and perennial ryegrass at 150 g m^{-2}; in 2011, Kentucky bluegrass was seeded at 15 g m^{-2} and perennial ryegrass at 35 g m^{-2} and plots were seeded by hand on initiation dates. After seed was distributed, it was immediately cleated-in with four passes from a GA-SCW traffic simulator with cleated rollers and a differential slip action (Carrow et al., 2001).

During spring establishment in both years, traffic treatments began nine weeks after planting; for fall establishment, traffic treatments began 2 weeks after planting in 2010 and 3 weeks after planting in 2011. Spring 2010 traffic treatments began on 17 June and were applied weekly until 8 October, resulting in 64 passes for the 4 passes wk^{-1} treatment and 128 passes for the 8 passes wk^{-1} treatment. Fall 2010 traffic treatments were applied weekly from 24 September to 11 November, totaling 28 passes for 4 passes wk^{-1} and 56 passes for 8 passes wk^{-1}. In spring 2011, traffic treatments were applied weekly from 7 July to 10 November, totaling 76 passes for 4 passes wk^{-1} and 152 for 8 passes wk^{-1}. Lastly, in fall 2011, traffic treatments were applied weekly from 21 September to 10 November, totaling 32 passes for 4 passes wk^{-1} and 64 passes for 8 passes wk^{-1}.

A single pass of the traffic simulator was equal to operating the machine over a plot one time in one direction. The GA-SCW traffic simulator applied 6.03 cleat dents dm^{-2} in a single pass and that is equal to the number of cleat dents for one professional football game as described by Cockerham (1989). The first pass was always done in reverse and the second in the forward direction so that the smooth rear roller provided a final flattening of the dimpled surface.

Plots were mowed twice weekly at 5 cm with clippings returned, and watered as needed to promote seed establishment, plant growth, and to prevent drought stress. The strategy for water management was to irrigate to a target amount of 25.0 mm wk^{-1} from Friday through Tuesday, allowing plots to dry sufficiently by Thursday so traffic could be applied on a firm and non muddy surface. No further pesticides were used during the 2010 study for either species. For spring 2011 Kentucky bluegrass, mesotrione (Tenacity®) herbicide was applied at 290 mL ha^{-1}, starting on 20 May and repeated on ten day intervals for a total of four applications. No herbicides were used on perennial ryegrass in 2011 as speed of germination and maturity denied weed invasion. No herbicides were used on fall 2011 Kentucky bluegrass. Azoxystrobin (Heritage®) G fungicide was applied at 1.0 g m^2 on both species on 30 May, 25 June, and 23 July 2011 as a preventive measure.

Data for percentage turf cover and color were collected nine times during the 2010 spring study, 4 times for the fall 2010 study, 19 times in spring 2011, and 8 times in fall 2011. Data were generated via digital images taken with a Canon PowerShot P1 IS digital camera (Canon, USA) housed in a standardized lightbox (NextGen Research, Willamette Valley, OR, USA). Digital images were batch processed with SigmaScan Pro 5 (SPSS, Inc., Chicago, IL, USA) and data were extracted as described in Richardson et al. (2001) for percentage cover and for turfgrass color as described in Karcher and Richardson (2003).

Data for percentage cover and turfgrass color were analyzed with PROC MIXED in SAS Statistical Software (SAS Inc, Cary, NC, USA) individually for each species and on for each sample date.

Results and Discussion

Results will be presented separately for 2010 and 2011 due to changes in experimental design between years.

Spring 2010 – Kentucky bluegrass

Nitrogen rate did not affect percentage cover of spring established Kentucky bluegrass on any sample date but did affect turf color on 13 July and 18 August, sample dates six and seven (Table 1). There were no interactions between nitrogen rate and traffic level (Table 1).

On sample date six, 13 July, increasing nitrogen rate to 300 kg ha^{-1} resulted in better turf color when compared to 100 kg ha^{-1} but not 200 ka ha^{-1}; further increases beyond 300 ka ha^{-1} did not improve turf color (Fig. 1). On the following sample date, 18 August, increasing nitrogen rate to 400 kg ha^{-1} resulted in better turf color when compared to 100 and 200 kg ha^{-1} but not 300 kg ha^{-1} (Fig. 1). On most sample dates, there was no difference between nitrogen rates and we felt that our seeding rate was too high and masked effect of nitrogen throughout the study, leading us to use lower seeding rates in 2011.

Contrary to results from Beard (1973) and Canaway (1984), we found that increases in nitrogen did not affect traffic tolerance because percentage cover did not differ among nitrogen rates at any point during the study.

Spring 2010 – Perennial ryegrass

Nitrogen rate affected color and cover on six of nine sample dates (Table 2). Trends changed as the growing season progressed, but in general 200 kg total N ha^{-1} resulted in the most consistent color ratings (Fig. 2). A lack of mean separation on the last three sample dates reaffirmed our conclusion that effects of nitrogen rate were masked by high seeding rates and increasing nitrogen may not be necessary for rapid establishment of perennial ryegrass in fall when seeded at 150 g m^2.

Increases in nitrogen rate above 100 ka ha^{-1} generally resulted in greater turf cover and to what degree depended on sample date (Fig. 3). We recommend that turf managers apply a minimum of 200 kg total N ha^{-1} during an eight week spring establishment period to maximize turf cover prior to traffic. This recommendation follows Canaway (1983) who concluded that aboveground biomass is the most important single variable in relation to shear strength and ball bounce resilience of athletic fields prior to wear.

Fall 2010 – Kentucky bluegrass and perennial ryegrass

Due to a lack of significant results from the fall 2010 establishment for both species, the resulting data and results were omitted. Above normal seeding rates masked nitrogen effects even more than in spring 2010 and resulted in no main effect of nitrogen rate on any sample date during the fall season.

Spring 2011 – Kentucky bluegrass

Nitrogen rate affected percentage cover on eighteen of nineteen sample dates, while turf color was affected on seventeen of nineteen sample dates (Table 3), indicating that nitrogen effects were more prevalent in spring 2011 than spring 2010. Interactions between nitrogen rate and traffic level occurred sporadically throughout the sampling period and when they did, were interactions of magnitude, i.e. at traffic level 0 passes wk^{-1}, increasing nitrogen rate resulted in greater turf cover or color when compared to 4 or 8 passes wk^{-1}, as cumulative traffic degraded both turf cover and color as the season progressed.

For the period 31 May through 15 Oct, nitrogen rates of 200, 300, and 400 kg ha^{-1} rarely differed in their effect on turf color (Fig. 4). By the end of the study, 14 November 2011, nitrogen rates of 300 and 400 kg ha^{-1} did not differ and provided the greatest turf color values of 6 and 6.4, respectively (Fig. 4). Rates of 0, 100, and 200 kg total N ha^{-1} differed and provided turf color ratings of 4.0, 4.5, and 5.3, respectively, by the end of the study (Fig. 4).

Increases above 0 kg N ha^{-1} generally resulted in increased turf cover through 31 August; by 8 July, increases above 100 kg N ha^{-1} resulted in increased turf cover. However, 200, 300, and 400 kg N ha^{-1} rarely differed during the first half of the sampling period (Fig. 5). By 14 November, increases beyond 100 kg total N ha^{-1} resulted in incrementally greater turf cover up to 400 kg total N ha^{-1}, which resulted in the greatest turf cover at 38.1% (Fig. 5).

Based on these findings, we conclude that 300 kg total N ha^{-1} can be applied during the first eight weeks of spring establishment of Kentucky bluegrass to provide the best and longest lasting turf color, and up to 400 kg total N ha^{-1} to maximize turf cover throughout a growing season. We have shown that increases up to 300 kg total N ha^{-1} result in increases in turf color, beyond findings from Hummel (1980) who saw the best turf color ratings with 97 kg N ha^{-1}.

Further, our findings contrast Beard (1973) and Canaway (1984) who indicated that excessive nitrogen will negatively impact traffic tolerance. We showed that increases up to 300 and 400 kg total N ha^{-1} provided the best color and percentage cover, respectively, above the 200 – 300 kg N ha^{-1} reported by Canaway (1984).

Fall 2011 – Kentucky bluegrass

Nitrogen rate affected percentage cover on all but the first sample date and affected turf color on every sample date (Table 4). As with spring established Kentucky bluegrass, interactions of magnitude occurred between nitrogen rate and traffic level as damage accrued, i.e. nitrogen rate effects were the same at each traffic level but with larger differences between them as traffic level increased.

Nitrogen rate had opposite effect in fall compared to spring; increases in nitrogen rate above 100 kg ha^{-1} resulted in decreased turf color (Fig. 6). For a majority of sample dates, rates of 300 and 400 kg ha^{-1} did not differ and provided the lowest color ratings (Fig. 6). By 14 November, 200 - 400 kg total N ha^{-1} along with the untreated control differed from 100 kg N ha^{-1}, which consistently provided the best turf color (Fig. 6). Seasonal growth patterns may be responsible for the difference in results between spring and fall establishment. Additionally, traffic initiation relative to nitrogen applications may have compounded detrimental effects of increases in nitrogen rate. Moreover, increases beyond 100 kg N ha^{-1} negatively impacted turf color and are not recommended during fall establishment. These results are similar Hummel (1980) who found optimal color from 97 kg N ha^{-1} when compared to 48 kg N ha^{-1}.

There was no difference in turf cover between nitrogen rates for the first sample date and for the remainder of the season, 100 kg N ha^{-1} resulted in the greatest turf cover (Fig. 7). Where differences existed, they were inversely linear; turf cover decreased as nitrogen rate increased with the exception of the untreated control that was in the midrange for most sample dates and differing only from 400 kg N ha^{-1} by the end of the study (Fig. 7). These findings are similar to Hummel (1980) who found that 97 kg N ha^{-1} resulted in more rapid establishment when compared to 48 kg N ha^{-1}. Seasonal growth patterns may have been responsible for the difference in nitrogen response between fall and spring.

Spring 2011 – Perennial ryegrass

Nitrogen rate affected both percentage cover and color on every sample date (Table 5). Few interactions between nitrogen rate and traffic level were present; none for color response and only on the final two sample dates for percentage cover (Table 5); those present were due to attrition caused by traffic and resulted in differences in magnitude with the same order, i.e. differences between nitrogen rates increased with traffic level.

Increases in nitrogen rate beyond 0 kg ha^{-1} resulted in increased turf color on all but two sample dates; moreover, after 27 July, incremental increases in nitrogen rate from 0 to 300 kg ha^{-1} had an incrementally positive effect on turf color (Fig. 8). Beginning 5 October, increases from 300 to 400 kg total N ha^{-1} resulted in further increases in turf color for the remainder of the study (Fig. 8). These results show that for spring established perennial ryegrass, 400 kg total N ha^{-1} applied in the first eight weeks of establishment will have the longest lasting effect on turf color throughout a full growing season.

With the exception of the 25 Aug. sample date, increases above 0 kg N ha^{-1} resulted in increased turf cover (Fig. 9). Turf managers establishing perennial ryegrass in spring will maximize turf cover with early, frequent applications of urea totaling 400 kg N ha^{-1} starting one week after seeding for eight weeks.

As with spring established Kentucky bluegrass, our findings suggest that increases in nitrogen rate during establishment, from 300 – 400 kg ha^{-1}, above that found in the past 97 kg ha^{-1} (Hummel, 1980), and 200 – 300 kg ha^{-1} (Leyer and Skirde, 1980; Canaway, 1984) can further improve turf color and percentage cover of spring established perennial ryegrass without reducing traffic tolerance. Using urea to accomplish this is supported by Turner & Hummel (1992) who indicate that turfgrasses are more rapidly established with sources of nitrogen that are readily available.

Fall 2011 – Perennial ryegrass

Nitrogen rate affected both percentage cover and turf color on each sample date (Table 6). There were no interactions between nitrogen rate and traffic level for the first two sample dates on cover or color, but interactions were present on the remaining sample dates for both responses (Table 6). Again, these were interactions of magnitude that resulted from the detrimental effects of traffic; for 0 passes wk^{-1}, turf cover and color were greater when compared to 4 and 8 passes wk^{-1}.

Contrary to spring established perennial ryegrass, increases in nitrogen rate above 100 kg ha^{-1} generally decreased turf color (Fig. 10). Despite low initial color ratings from the untreated control, it provided equal color to 100 kg N ha^{-1} on four of the final five sample dates (Fig. 10). However, by the end of 2011, 100 kg N ha^{-1} resulted in the highest color ratings (Fig. 10).

Following a similar trend as color ratings, percentage cover response from nitrogen rate did not increase with rates above 100 kg total N ha^{-1} throughout the sampling period (Fig. 11). Further, after 28 September, increasing nitrogen rate beyond 0 kg ha^{-1} showed no increase in percentage cover (Fig. 11). These results suggest that nitrogen rate plays a more important role in maintaining turf color than percentage cover of fall established perennial ryegrass, contrasting

Minner and Valverde (2005) who concluded that visual observation of turfgrass cover decreases more than visual observation of turfgrass quality, of which color is a major component, as traffic injury accumulates.

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Table 1. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for spring established Kentucky bluegrass percentage cover and color on nine sample dates in 2010.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Spring 2010	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
17 May	NS	NS	NS	*	NS	NS
25 May	NS	NS	*	NS	NS	NS
1 June	NS	NS	*	NS	NS	NS
14 June	NS	NS	**	NS	NS	NS
30 June	NS	NS	**	*	NS	NS
13 July	NS	*	**	**	NS	NS
18 August	NS	*	**	**	NS	NS
15 September	NS	NS	**	**	NS	NS
11 October	N/A	NS	N/A	N/A	N/A	N/A

** Significant at 0.01 probability level

* Significant at 0.05 probability level

Table 2. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for spring established perennial ryegrass percentage cover and color on nine sample dates in 2010.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Spring 2010	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
17 May	*	*	NS	*	NS	NS
25 May	*	**	NS	*	NS	NS
1 June	NS	**	NS	**	NS	NS
14 June	NS	**	NS	**	NS	NS
30 June	*	**	**	**	NS	NS
13 July	**	**	**	**	NS	NS
18 August	**	NS	**	**	NS	NS
15 September	*	NS	**	**	NS	NS
11 October	NS	NS	**	N/A	NS	NS

** Significant at 0.01 probability level

* Significant at 0.05 probability level

Table 3. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for spring established Kentucky bluegrass percentage cover and color on nineteen sample dates in 2011.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Spring 2011	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
31 May	*	NS	NS	*	NS	NS
8 June	**	**	NS	NS	NS	NS
29 June	**	**	*	**	NS	*
8 July	**	**	*	**	NS	NS
14 July	**	**	**	**	*	NS
27 July	**	**	**	**	*	*
10 August	**	*	**	**	*	NS
12 August	**	**	**	**	*	NS
15 August	**	**	**	**	**	*
25 August	NS	NS	**	**	NS	NS
31 August	**	*	**	**	NS	NS
12 September	**	**	**	**	NS	*
15 September	**	**	**	**	*	NS
22 September	**	**	**	**	**	*
5 October	**	**	**	**	**	**
12 October	**	**	**	**	**	*
20 October	**	**	**	**	**	**
27 October	**	**	**	**	**	**
14 November	**	**	**	**	**	**

** Significant at 0.01 probability level

* Significant at 0.05 probability level

Table 4. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for fall established Kentucky bluegrass percentage cover and color on eight sample dates in 2011.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Fall 2011	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
15 September	NS	**	NS	**	NS	NS
21 September	**	**	*	**	NS	NS
28 September	**	**	**	**	**	**
5 October	**	**	**	**	**	**
12 October	**	**	**	**	**	**
20 October	**	**	**	**	**	**
27 October	**	**	**	**	**	**
14 November	**	**	**	**	**	**

** Significant at 0.01 probability level

* Significant at 0.05 probability level

Table 5. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for spring established perennial ryegrass percentage cover and color on nineteen sample dates in 2011.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Spring 2011	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
31 May	**	**	NS	NS	NS	NS
8 June	**	**	NS	NS	NS	NS
29 June	**	**	NS	NS	NS	NS
8 July	**	**	**	NS	NS	NS
14 July	**	**	**	**	NS	NS
27 July	**	**	**	**	NS	NS
10 August	**	**	**	**	NS	NS
12 August	**	**	**	**	NS	NS
15 August	**	**	**	**	NS	NS
25 August	**	**	**	**	NS	NS
31 August	**	**	**	**	NS	NS
12 September	**	**	**	NS	NS	NS
15 September	**	**	**	**	NS	NS
22 September	**	**	**	*	NS	NS
5 October	**	**	**	**	NS	NS
12 October	**	**	**	**	NS	NS
20 October	**	**	**	**	NS	NS
27 October	**	**	**	**	*	NS
14 November	**	**	**	**	*	NS

** Significant at 0.01 probability level

* Significant at 0.05 probability level

Table 6. Type III tests of fixed effects of nitrogen rate, traffic rate, and their interaction for fall established perennial ryegrass percentage cover and color on eight sample dates in 2011.

	Source (df)					
	Nitrogen (4)		Traffic (2)		Nit*Traffic (8)	
Fall 2011	Pr > F		Pr > F		Pr > F	
Sample Date	Cover	Color	Cover	Color	Cover	Color
15 September	*	*	NS	NS	NS	NS
21 September	*	**	NS	*	NS	NS
28 September	**	**	**	**	*	**
5 October	**	**	**	**	*	**
12 October	**	**	**	**	**	**
20 October	**	**	**	**	**	**
27 October	**	**	**	**	**	**
14 November	**	**	**	**	**	**

** Significant at 0.01 probability level

* Significant at 0.05 probability level

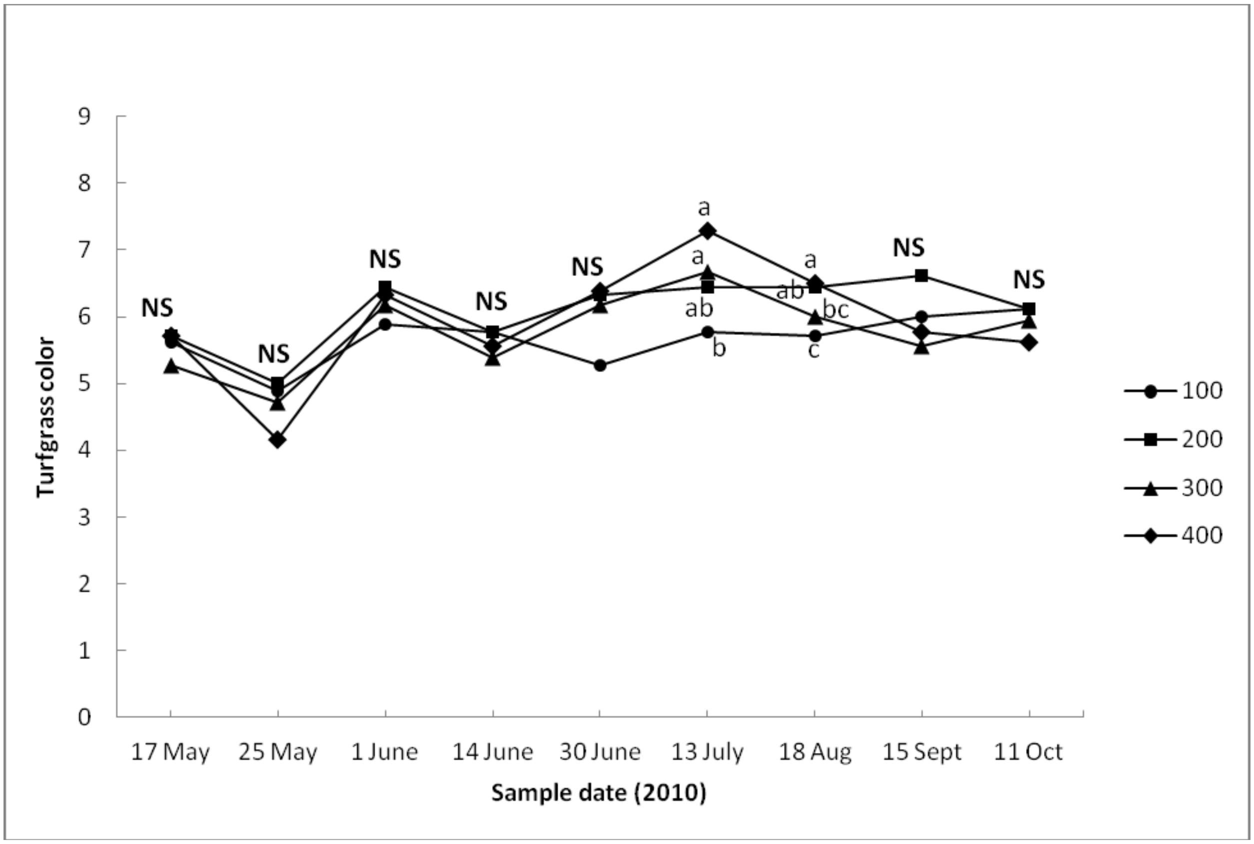

Figure 1. Turfgrass color ratings for spring established Kentucky bluegrass with four different nitrogen rates (in kg N ha^{-1}) over nine sample dates between 17 May and 11 October 2010. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

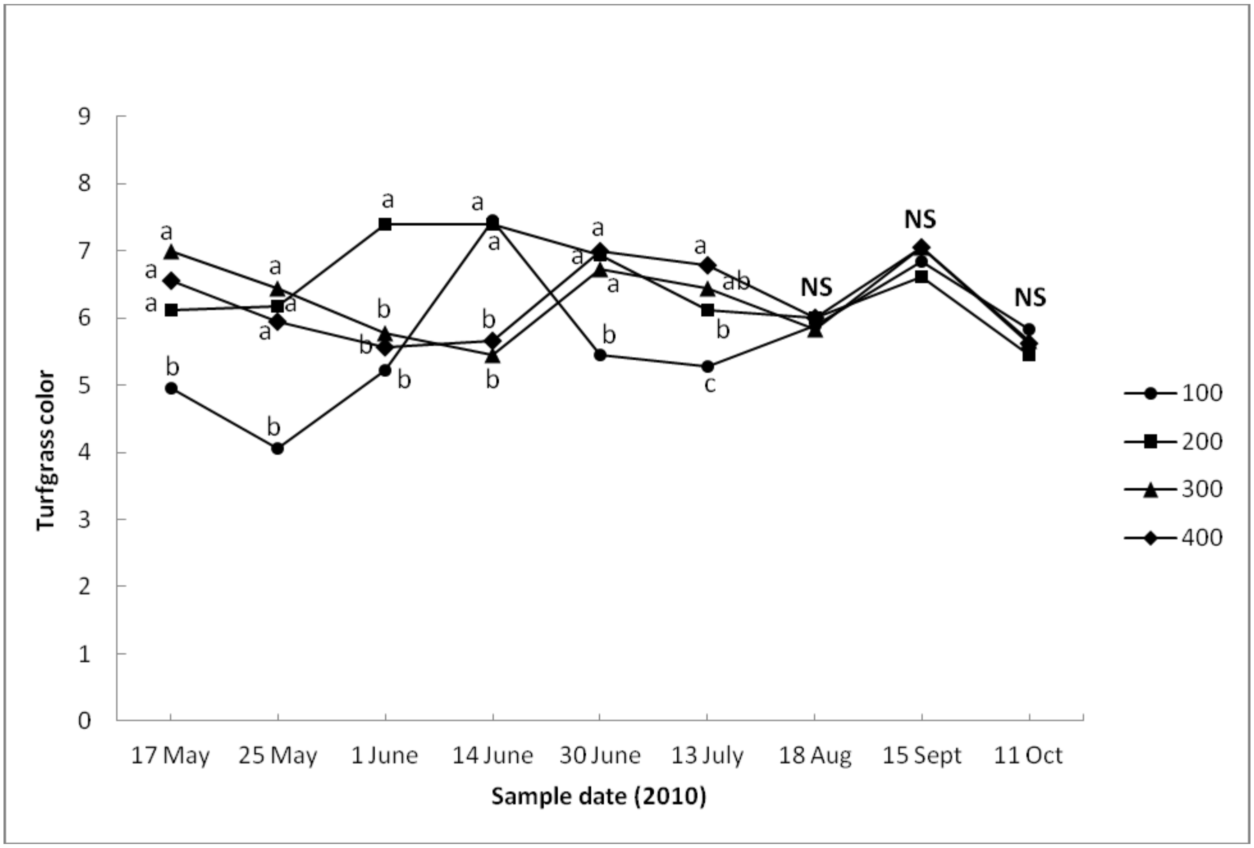

Figure 2. Turfgrass color ratings for spring established perennial ryegrass with four different nitrogen rates (in kg N ha^{-1}) over nine sample dates between 17 May and 11 October 2010. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

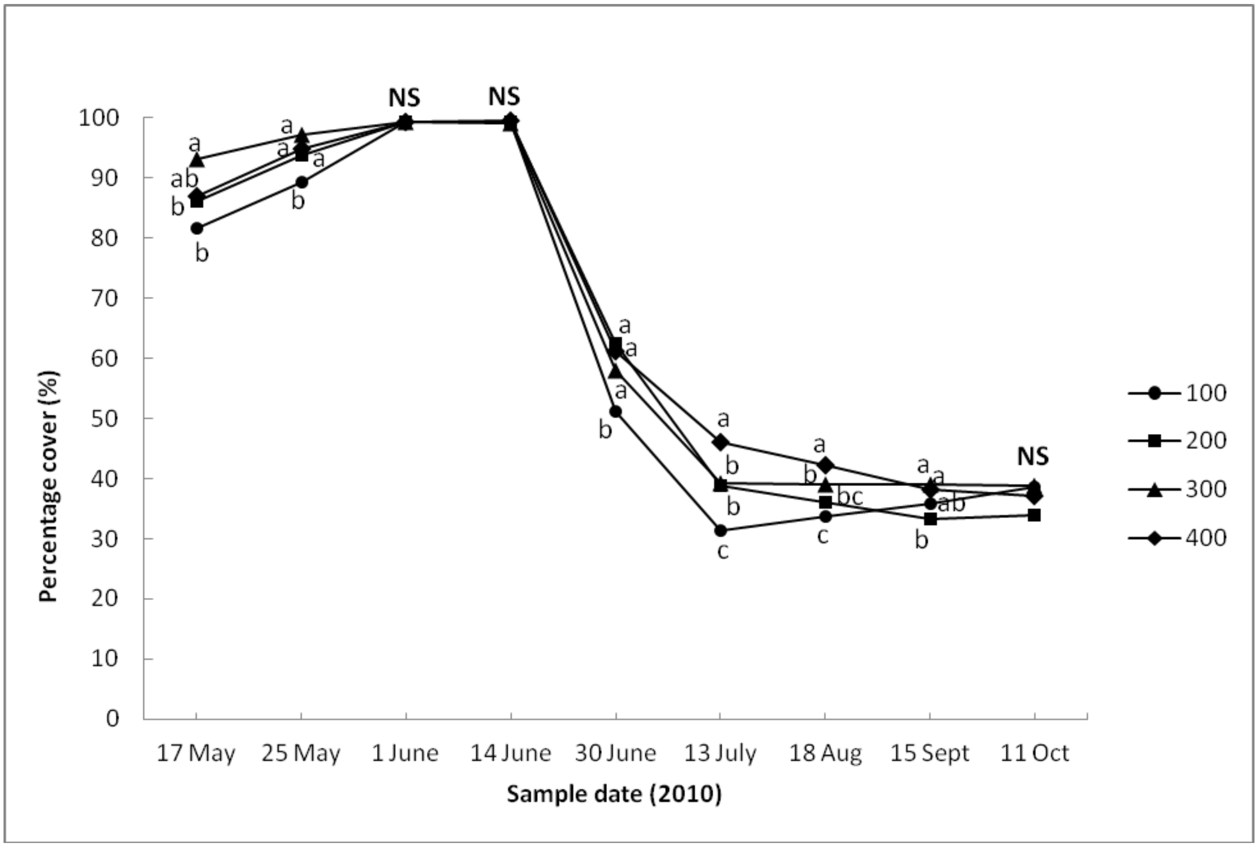

Figure 3. Percentage cover of spring established perennial ryegrass with four different nitrogen rates (in kg N ha^{-1}) over nine sample dates between 17 May and 11 October 2010. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

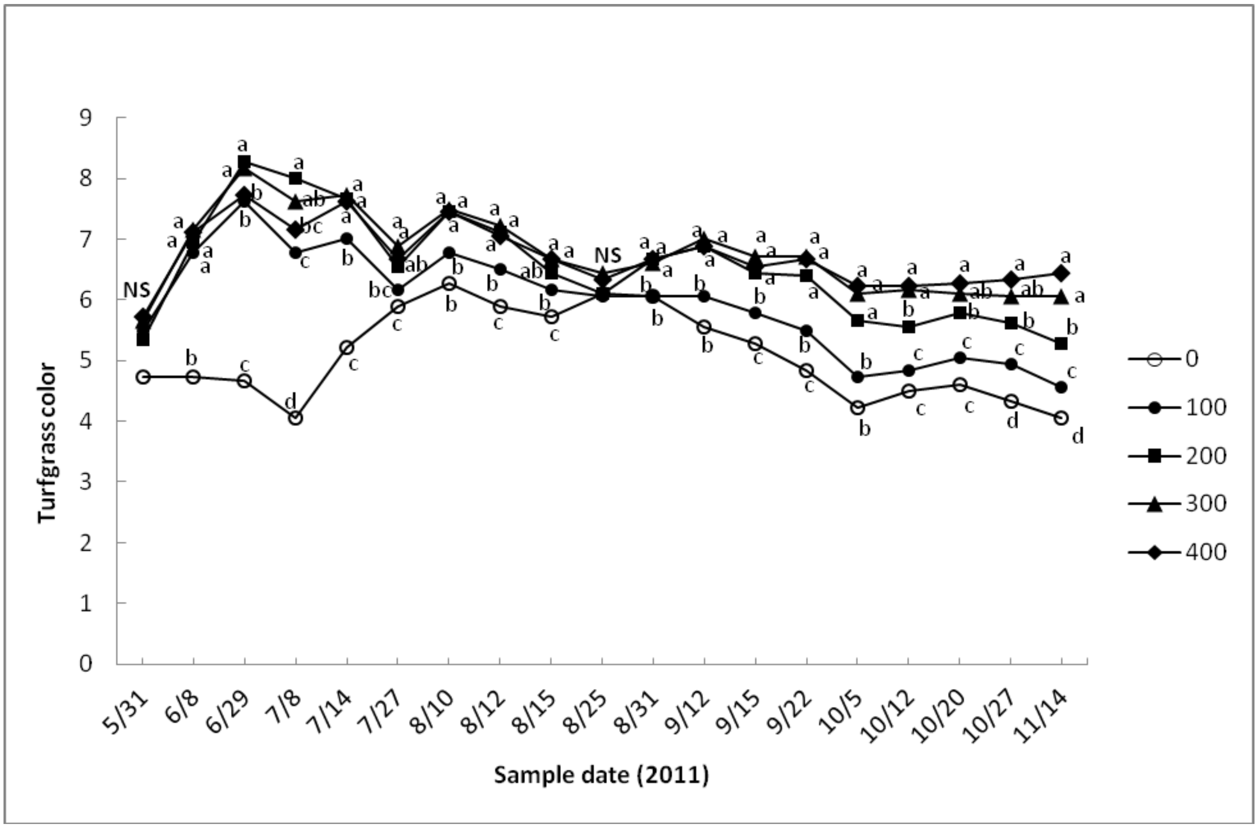

Figure 4. Turfgrass color ratings for spring established Kentucky bluegrass with five different nitrogen rates (in kg N ha^{-1}) over nineteen sample dates between 31 May and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

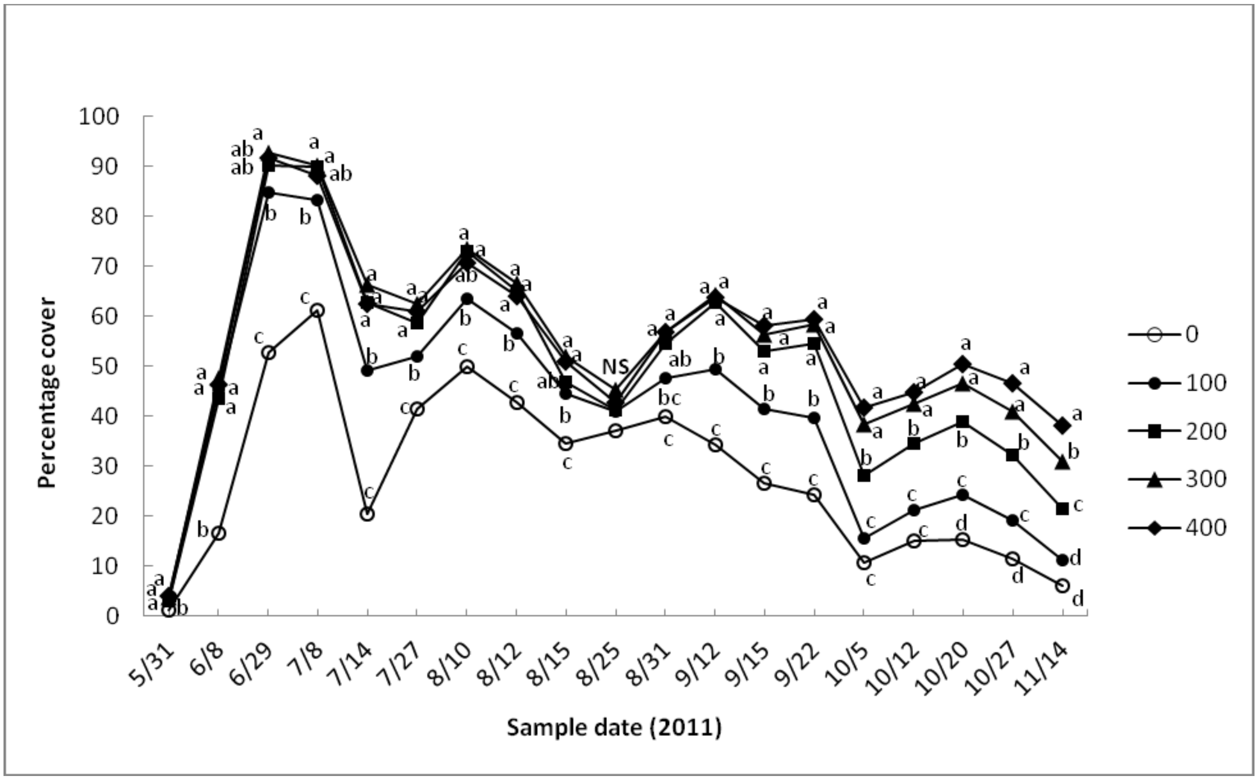

Figure 5. Percentage cover of spring established Kentucky bluegrass with five different nitrogen rates (in kg N ha^{-1}) over nineteen sample dates between 31 May and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

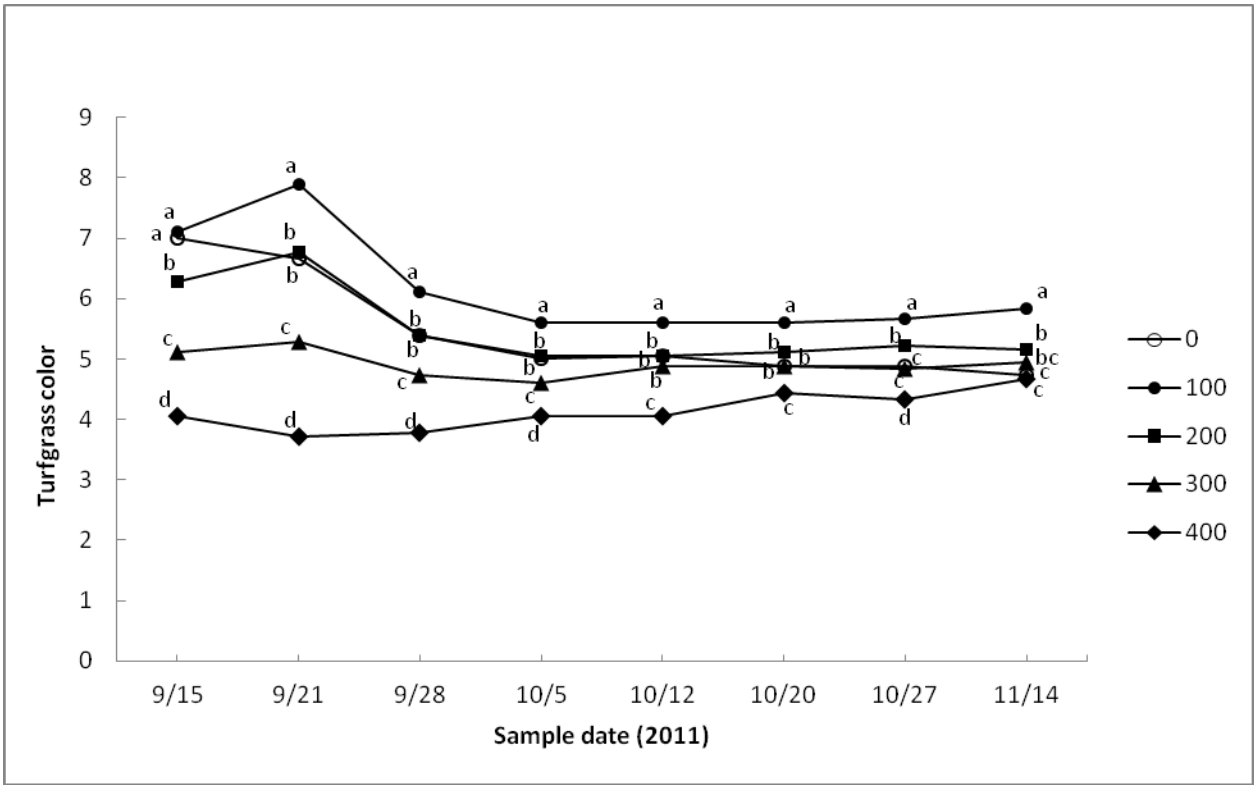

Figure 6. Turfgrass color ratings for fall established Kentucky bluegrass with five different nitrogen rates (in kg N ha^{-1}) over eight sample dates between 15 Sept and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different.

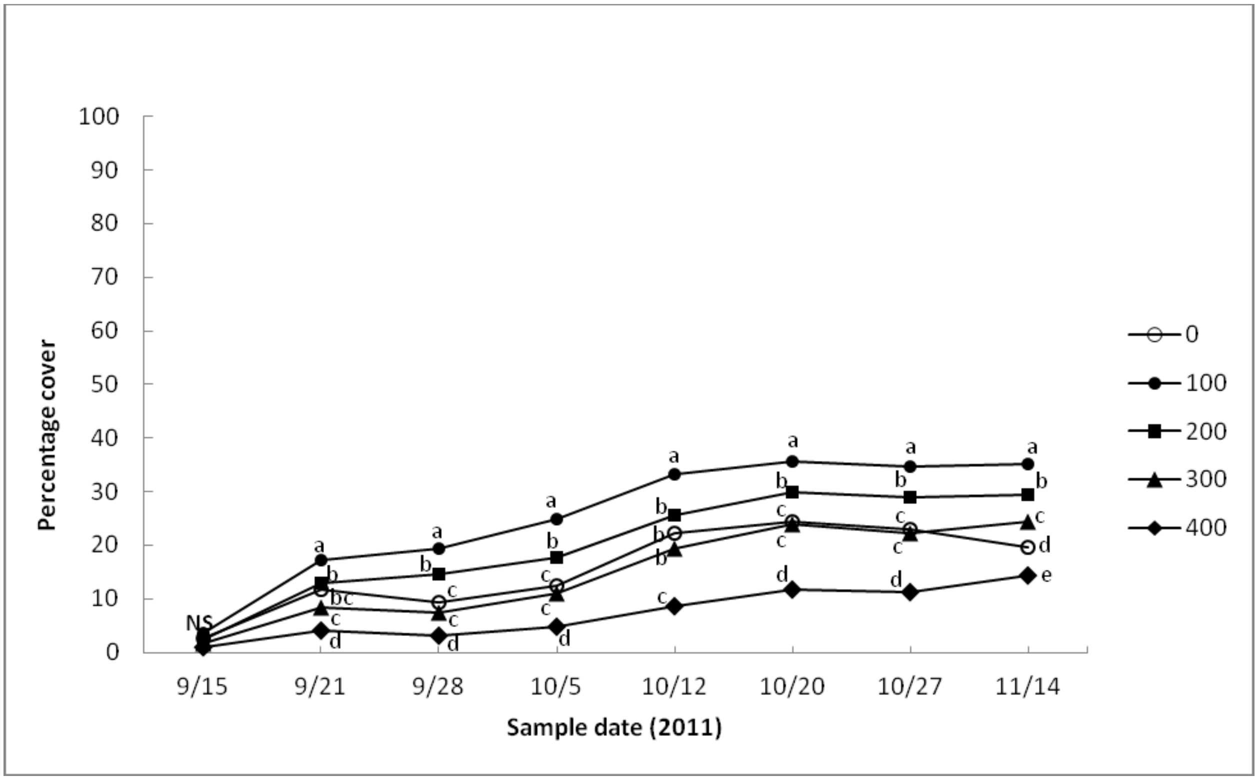

Figure 7. Percentage cover of fall established Kentucky bluegrass with five different nitrogen rates (in kg N ha^{-1}) over eight sample dates between 15 Sept and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with α = 0.05. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

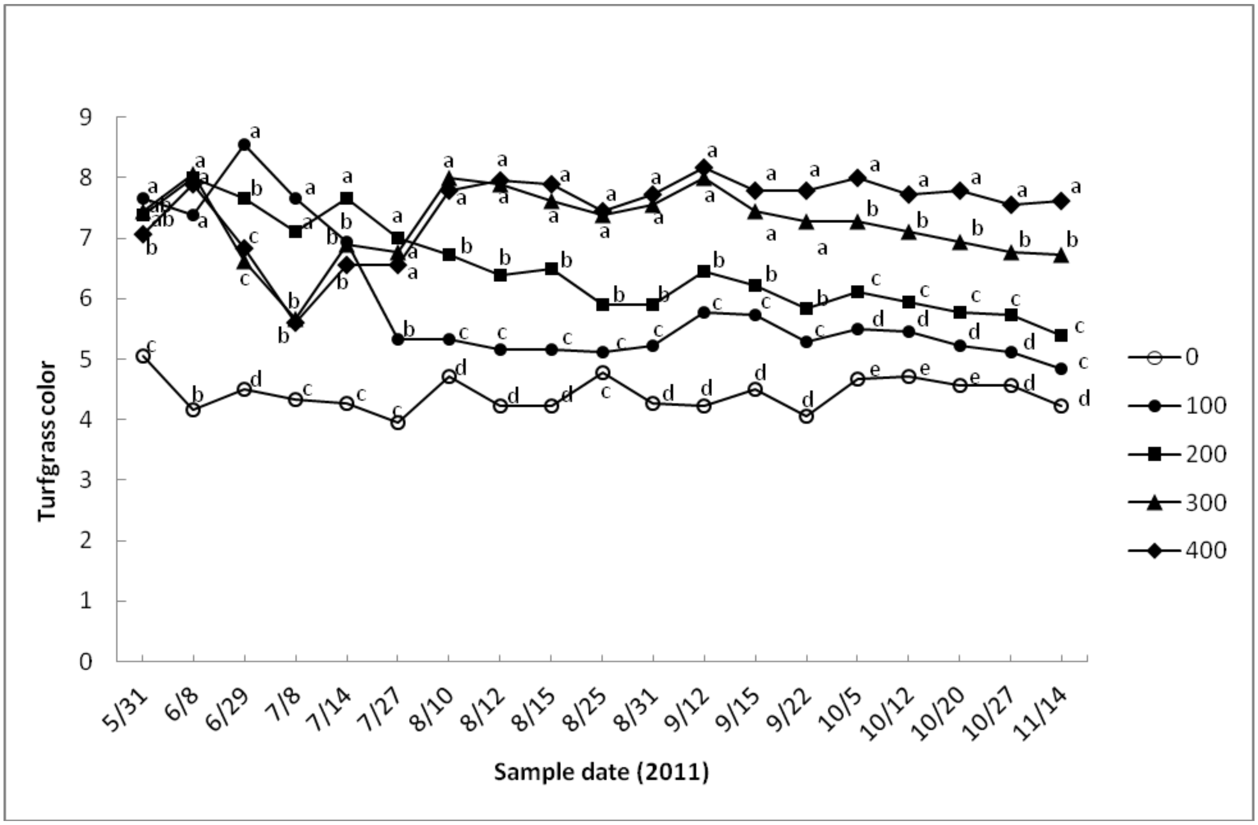

Figure 8. Turfgrass color ratings for spring established perennial ryegrass with five different nitrogen rates (in kg N ha^{-1}) over nineteen sample dates between 31 May and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different and NS indicates no differences between nitrogen rates on that sample date.

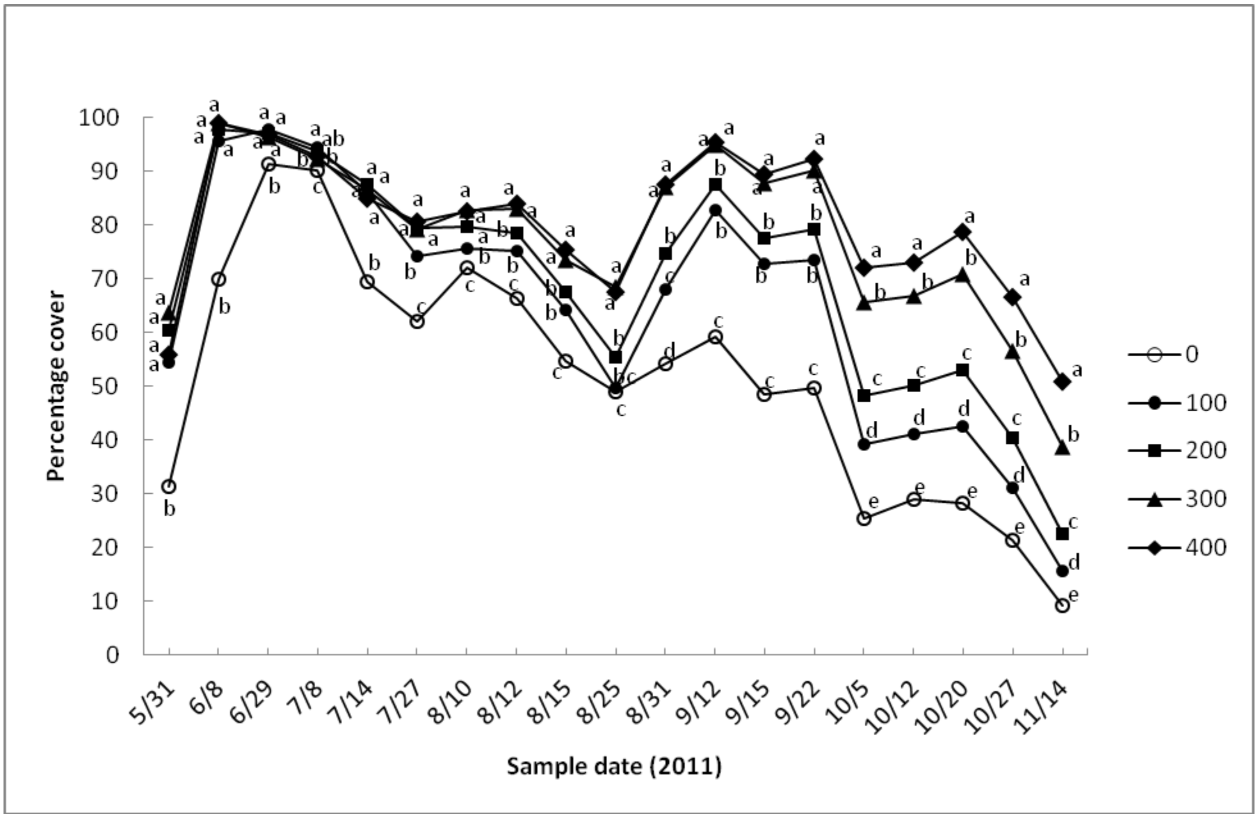

Figure 9. Percentage cover of spring established perennial ryegrass with five different nitrogen rates (in kg N ha^{-1}) over nineteen sample dates between 31 May and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different.

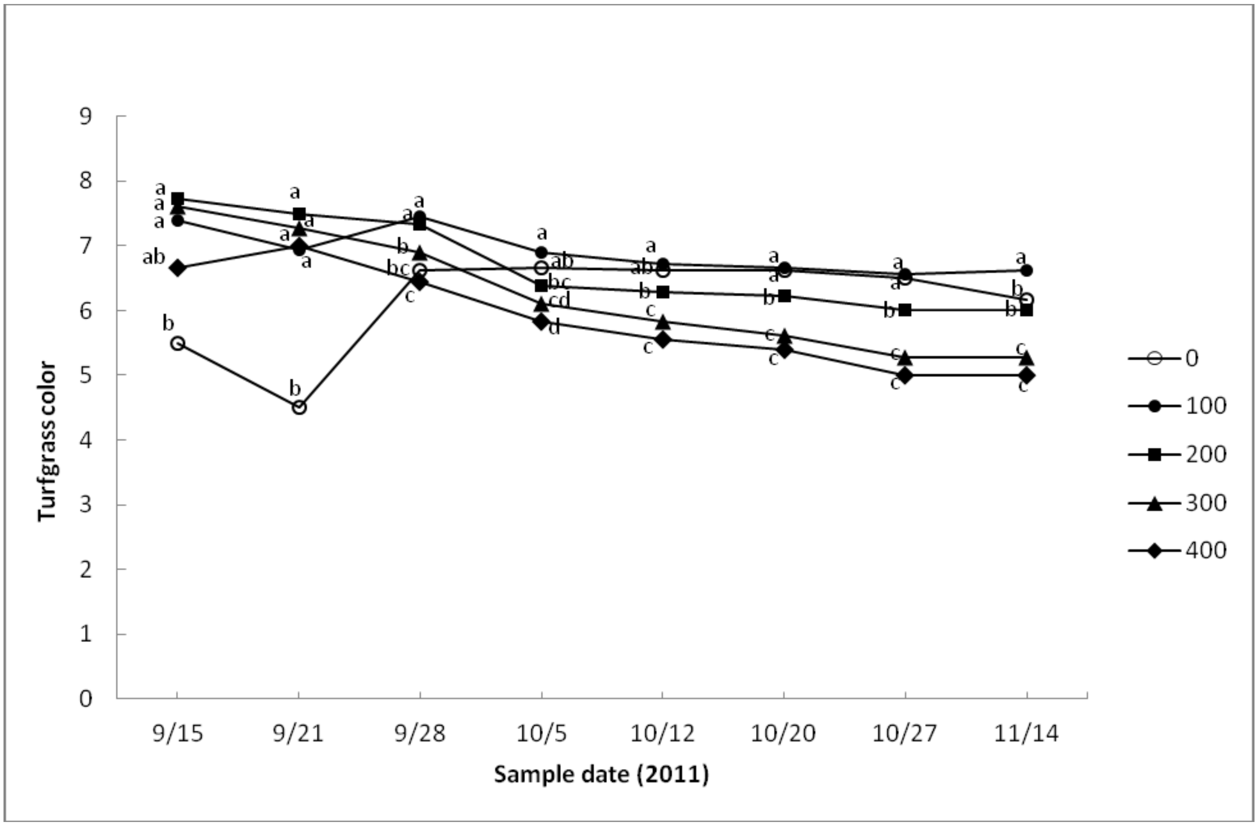

Figure 10. Turfgrass color ratings for fall established perennial ryegrass with five different nitrogen rates (in kg N ha^{-1}) over eight sample dates between 15 September and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different.

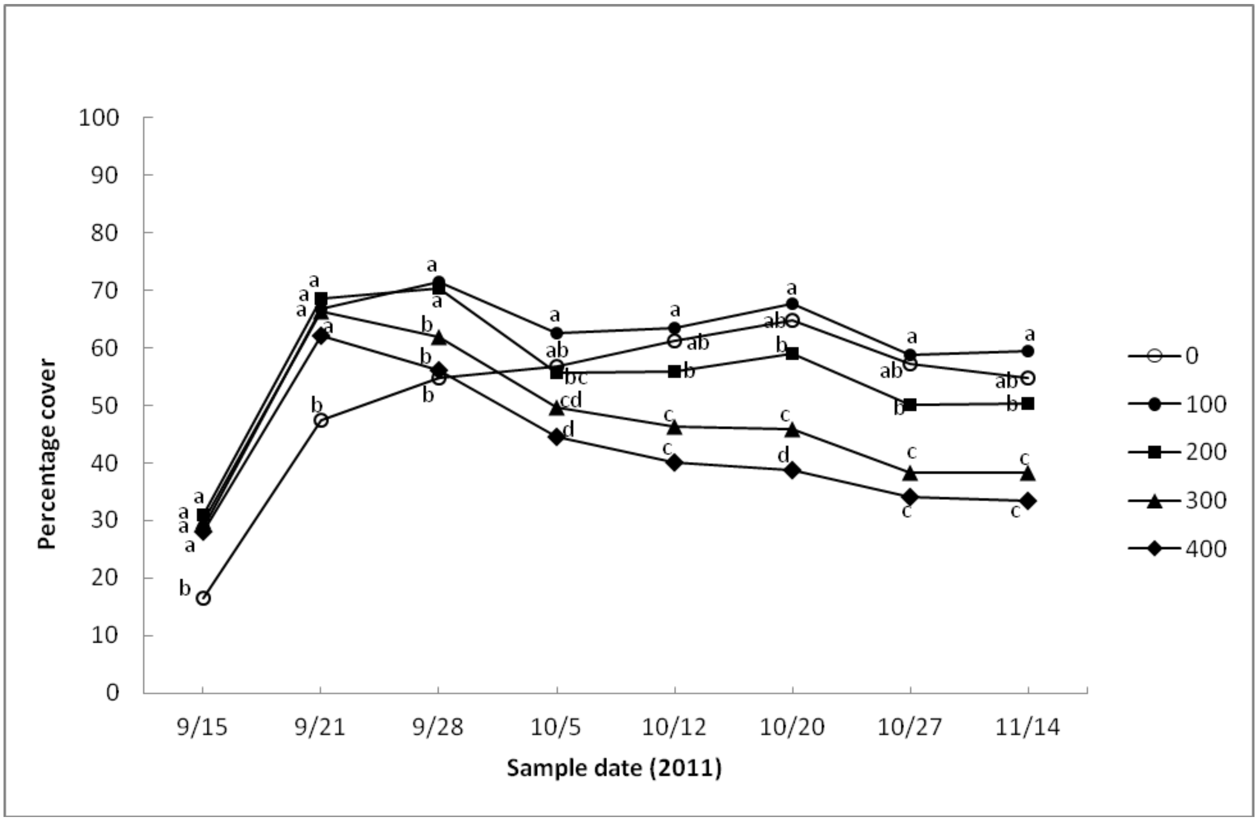

Figure 11. Percentage cover of fall established perennial ryegrass with five different nitrogen rates (in kg N ha^{-1}) over eight sample dates between 15 September and 14 November 2011. Means result from three replications averaged over three traffic levels and are separated by Fisher's protected F-test with $\alpha = 0.05$. Means with the same letter are not different.

GENERAL CONCLUSIONS

Seedbanking potential

Our results indicate that when starting from bare ground, Kentucky bluegrass and perennial ryegrass do not exhibit long term viability under simulated traffic. When examining two different seeding schedules, one time versus multiple, we have shown that viable seed is only available in extracted cores from plots that received multiple seedings. Determining which multiple seeding event is responsible for the viable seed extracted cannot be resolved as tracking of individual seeding events is difficult. Little seed germinated from cores extracted from the single seeding schedule and under either schedule, small numbers of germinated seedlings were present for any sample taken more than three months after planting.

A single seeding was always more beneficial in terms of percentage cover; still, balance can be achieved with a heavy seeding early in autumn, followed by repeated, lower rate applications into mid October to provide a source of fresh, viable seed that will provide green cover later into the season as attrition from traffic wears away grass from the initial seeding. Our results address Stier (2008), Hoiberg et al. (2009) and Sherratt et al. (2009) who indicate the need for scientific research on seedbank formation in turfgrasses and whether a true seedbank is being formed or if turf managers are simply providing a fresh source of seed via over-seeding late into the season.

Seeding rate did have an impact on emerged seedlings from cores, particularly for perennial ryegrass, as increases in seeding rate resulted in increased seedlings emerged. Perennial ryegrass seeded at 450 g m^{-2} resulted in 199.3 emerged seedlings from cores sampled three months after seeding, which represents an equivalent seeding rate of 50 g m^{-2}. However, by the following spring, numbers dropped to 30.8 emerged seedlings, representing an equivalent seeding rate of 7.5 g m^{-2}, and one year after seeding, there was no seed available from harvested cores. Is the number of seedlings that emerged at the end of the initial planting season is enough to reestablish worn areas the following spring? We conclude that numbers found in our study will not eliminate the need for turf managers to reseed worn areas the following spring.

Seeding rate also affected percentage cover, as incremental increases in seeding rate resulted in incremental increases in percentage cover for both species, from 30 – 120 g m^{-2} for Kentucky bluegrass, and 150 – 450 g m^{-2} for perennial ryegrass. These results coincide with results from Hoiberg et al. (2009) who found that increases in seeding rate of annual ryegrass up to 450 g m^{-2} resulted in the greatest turf cover. Further, Minner et al. (2008) found perennial ryegrass cover incrementally increased as seeding rate increased from 25 to 125 g m^{-2} and that in general, Kentucky bluegrass turf cover increased as seeding rate increased.

Tracking seed via burial in mesh bags provided similar results to counting emerged seedlings from cores. In both Kentucky bluegrass and perennial ryegrass, most seed germinated when buried at 2.5 cm, and of that that did not germinate, most was dead. Very few viable seeds were recovered on any sample date. These results indicate that when planted via player’s cleats, near a depth of 2.5 cm, viability in perennial ryegrass and Kentucky bluegrass is limited beyond autumn of the planting year; however, this could be due to buried seed achieving a high germination rate and leaving only dead seed behind. Our findings are similar to those from Garrison and Stier (2010) who found colonies of buried Kentucky bluegrass seed declined quickly or completely ceased to exist, and from Rampton and Ching (1966) who found that perennial ryegrass had very limited capacity for longevity and dormancy maintenance, suffering the most rapid deterioration of any seeds in their experiment. Further, our results support

Roberts (1981) who reported that due to synchronous germination in autumn, seeds from *Lolium multiflorum* and *Lolium perenne* make little or no contribution to the seedbank.

Nitrogen based establishment

Increasing nitrogen rate to quickly develop aboveground biomass during establishment of Kentucky bluegrass and perennial ryegrass appears dependent on many factors. In 2010, we attempted to combine increased seeding rate with increased nitrogen to expedite biomass development. We know from previous work by Minner et al. (2008) and Hoiberg et al. (2009) that increases in seeding rate help maximize turf cover when sown during traffic. We were interested to see if increased nitrogen could supplement this process and what we discovered is that increased seeding rate appeared to mask effects of increased nitrogen rate. Therefore, we lowered seeding rates closer to normal in 2011; Kentucky bluegrass from 25 to 15 g m^{-2} and perennial ryegrass from 150 to 35 g m^{-2}. Fewer differences among nitrogen rates with regard to turf color and percentage cover were present in the 2010 study when compared with 2011. Lowering seeding rate allowed us to more closely examine the effects increased nitrogen would have on expediting establishment.

Spring 2011 establishment saw similar trends in Kentucky bluegrass and perennial ryegrass. Applying urea in eight, equal applications totaling 300 – 400 kg N ha^{-1} resulted in the greatest turf color and percentage cover by the end of the sampling period for both species. Increasing nitrogen to improve color and speed establishment was examined by Madison (1962) who found that nitrogen fertilizer increased population density without greatly affecting individual plant size and by Hummel (1980) who reported more rapid establishment of Kentucky bluegrass and darker color with 97 kg N ha^{-1} when compared to 48 kg N ha^{-1}.

Since carbohydrate availability for protein synthesis can become limiting with increased nitrogen rates, subsequent traffic tolerance in this situation was an important consideration. Canaway (1984) found an initial increase in aboveground biomass, followed by a leveling off and eventual decline at very high levels of nitrogen, concluding an optimum level to maximize wear tolerance was 200 – 300 kg N ha^{-1} yr^{-1}. Leyer and Skirde (1980) also reported that increased nitrogen resulted in decreased wear tolerance, indicating the same threshold level as Canaway (1984) for maximizing traffic tolerance. However, our results show that increases in nitrogen up to 400 kg total N ha^{-1} during spring establishment in 2011 resulted in the most traffic tolerant turves of Kentucky bluegrass and perennial ryegrass. This may be due to the hardening off period that took place after urea applications ceased prior to traffic onset. Our results also show that applications of urea, historically known for its short lived response, were present throughout the growing season when applied at the rates and schedule in our study.

In contrast, when increased rates of nitrogen were examined during the 2011 fall establishment period, results were reversed. Increases above 100 kg total N ha^{-1} had negative effects on both color and cover of both species. We feel that nitrogen application relative to onset of traffic, i.e. without a hardening off period, and seasonal growth patterns are responsible for the difference in optimal nitrogen rate in spring versus fall establishment. Regardless, 100 kg total N ha^{-1} over the course of eight weeks appeared to provide maximum color and cover during fall establishment in both species.

We feel that turf managers can utilize the results from all three studies to help maximize turf cover and color on heavily trafficked areas that repeatedly need reestablishment. The importance of a heavy initial seeding during fall establishment appears more beneficial than trying to speed establishment with increased nitrogen rates. However, when spring establishment is possible, increasing nitrogen rate with a normal seeding rate will enable turf managers to maximize turf color and cover; additionally, herbicide use may be necessary to ensure the best possible stand of Kentucky bluegrass. Despite our findings regarding seedbank formation, turf managers should not be discouraged from using multiple inputs during the traffic season. Seed is relatively cheap and can be selectively applied to worn areas of athletic fields. To ensure a constant source of viable seed into the middle part of the traffic season, repeated, lower rate applications should be made and the action of player's cleats allowed to assist in providing seed to soil contact for germination.

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